RESOURCE & POTENTIAL RECLAMATION EVALUATION

Hanging Woman Creek · Study Area

EMRIA Report No. 12 · 1977

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
UNITED STATES GEOLOGICAL SURVEY

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16. Abstract (Limit: 200 words)

This report evaluates the geochemistry and hydrology of East Trail Creek, Montana, potential coal lease tract site. The report is interpretive in nature and presents a section on mining effects and reclamation alternatives.

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Evaluation of Reclamation Potential of Surface Mined Lands

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FOREWORD

The Hanging Woman study report is unique in the EMRIA program. All other study reports have been completed by the U.S. Bureau of Reclamation, while responsibility for producing this report was with the BLM. The study site was selected in FY 76 by the Montana State Office. At that time, Hanging Woman and one other site were considered to have number one priority. Funding and USBR personnel restrictions prevented studying both sites in the conventional manner.

At the same time, the Branch of Coal Resources, Geologic Division, U.S. Geological Survey was scheduled to map the Quietus and Forks Ranch 7 1/2 minute quad sheet for coal resources. We were also able to persuade the Montana Bureau of Mines and Geology to alter their drilling program to take in the study site. With the promise of solid cores, the Branch of Regional Geochemistry, Geologic Division, USGS, became interested in the project. The Montana District, Water Resources Division, USGS, were already working under a joint BLM/USGS agreement, thus it was possible to direct their efforts to the area.

All that remained was the crucial part of collating the report and the responsibility for production. This became a joint responsibility of the Division of Resources, Montana State Office and the Rehabilitation Data Staff, Denver Service Center.

The only problem that developed with this approach was the difference in "study site" boundaries. Geologic Division mapped on the original BLM tract selection (Figure 15). The hydrologic studies and soil survey information was developed for the entire watershed (Figure 24). The area mapped by Geologic Division is the only area that has strippable coal and has the potential to be disturbed. The entire watershed needed to be investigated to determine the hydrologic characteristics.

ACKNOWLEDGEMENTS

The Hanging Woman study report is comprised of several sections, each completed by a different author. The overall editing and collating of the report was the responsibility of the Rehabilitation Data Staff, Denver Service Center, and the Montana State Office, BLM. The Introduction, General Regional Description, Climate and Physiography sections were the responsibility of BLM. Geology and Coal Resources was written by W. C. Culbertson, J. R. Hatch and R. H. Affolter, Branch of Coal Resources, Geologic Division (GD), US Geological Survey (USGS), Denver, Colorado.

Overburden Chemistry and Mineralogy section is the result of a study by Todd K. Hinkley, Richard J. Ebens and Josephine G. Boerngen, Branch of Regional Geochemistry, GD, USGS. The Soils section of the report is divided into three subsections - General Description written by Mike Rollins, Montana State Office and Jim Wardlaw, Rehabilitation Data Staff; Soil Chemistry and Mineralogy by Ronald R. Tidball, Branch of Regional Geochemistry; Moisture Relation in Soils by Ruben Miller, Office of Public Lands Hydrology, USGS, Denver, Colorado.

Hydrology of the study area was authored by William Hotchkiss and Jeff Stoner, Montana District, Water Resources Division, USGS, Helena, Montana. The Sediment Yield subsection of Hydrology was developed by Lynn Shown, Office of Public Lands Hydrology. The Vegetation section was written by Farrel Branson, Office of Public Lands Hydrology.

Mining Effects and Reclamation Alternatives were developed by all the above authors and put into one section for easy referral by the user. All drafting, illustrations and art are the work of Ann Heath, Rehabilitation Data Staff. Overall editing, collating and typing was done by Rita Valdez, Rehabilitation Data Staff.

This report is truly an interagency cooperative effort. Without the overwhelming support, coordination and dedication of all the above, the report could not have been published.

Robert G. Delk, Rehabilitation Data Staff
Fred Waldhaus, Montana State Office
Project Coordinators

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OF

HANGING WOMAN CREEK STUDY AREA, MONTANA

INTRODUCTION

Our society by necessity is looking to the energy minerals of the Rocky Mountains and Northern Great Plains Coal Provinces for a quantity and quality source of bituminous, sub-bituminous and lignite fuels. It is the responsibility of the Department of the Interior and principally the Bureau of Land Management to meet these energy demands and at the same time provide the overall management guidance for acceptable reclamation of the actual lands subject to disturbance but also to ensure an acceptable non-degradation of the air, water, soils, vegetation, wildlife, and recreation of affected areas.

Purpose

The purpose of this study is to assure adequate data for choosing optimum reclamation objectives and for establishing appropriate data and interpretation for preparation of lease stipulations through site-specific pre-planning recommendations for mining and reclamation.

Objectives

1. To analyze and quantify environmental impacts from surface mining of energy minerals in Montana.
2. To provide resource and impact information to the leasing site selection procedures as set forth by the Secretary of the Interior.
3. To provide environmental resource information needed to implement effective reclamation and rehabilitation programs and for the development of meaningful lease stipulations as required by the mined land reclamation program.
4. To provide resource and impact information to support state and local regional development and land use planning efforts.
5. To determine the present and potential capability of the soil and geologic strata to support and maintain vegetation on known energy fuel deposits.
6. To provide physical and chemical data from which realistic stipulations may be prepared for energy mineral exploration, mining, and reclamation plans.
7. To provide data needed in the preparation of Enrivonmental Impact Statements, Environmental Analysis Records, and to aid in the review of mining and reclamation plans for proposed land disturbing activities in the vicinity of the study.

Authority

Federal Land Management Policy Act of 1976.

Responsibility

Bureau of Land Management

1. Selects reclamation study site areas for coordinated investigation of vegetation, soil, geologic structure, surface water, and ground water.
2. Procures easements and rights-of-way to conduct the studies.
3. Characterizes the climate of the study area.
4. Provides soil survey information.
5. Acts as Project Coordinator for field work and report preparation.
6. Distributes technical data, reports, and reclamation and rehabilitation recommendations to Bureau of Land Management field offices.

U.S. Geological Survey - Water Resources Division

1. Develops plant-soil moisture relationships.
2. Conducts vegetation and soil studies which will result in vegetation maps and related soil characteristics.
3. Assesses reclamation potential based on water available from precipitation, the effects of surface mining on area hydrology, and the measures required to prevent adverse effects on surface and ground waters of the area.
4. Prepares sediment yield maps.
5. Prepares erodibility maps.
6. Estimates annual runoff and peak flows.
7. Collection and interpretation of data to predict alternative solutions to ground-water problems encountered during mining and reclamation.
8. Implementation of a monitoring system to define base line conditions and to document ground-water changes in flow and quality caused by mining and reclamation.
9. Prepares potentiometric maps.

Branch of Coal Resources

1. Prepares a geologic map.
2. Coal sections and well logs.
3. Coal bed maps showing coal resources.
4. Tabulation of coal resources estimates.
5. Table of analytical results on coal resources.

Branch of Regional Geochemistry

1. Characterizes and interprets overburden materials as well as substrata immediately below the coal resources.
2. Provides soil map of the study area.

Montana Bureau of Mines and Geology

1. Conducts drilling operations for the procurement of core samples.
2. Installs casing in holes selected for ground water observation wells.

GENERAL REGIONAL DESCRIPTION

The Hanging Woman Creek study area lies within the Northern Rolling High Plains sub-region (66,500 mi^2) (172,000 km^2) of the Western Great Plains Range and Irrigated Region (217,000 mi^2) (562,000 km^2) USDA Handbook 296. Quoting from the Handbook:

Western Great Plains Range and Irrigated Region

"In this section of the Great Plains, unfavorable soils, strong slopes, or low moisture supplies make success at dry farming very uncertain. The annual precipitation ranges from 11 to 24 inches (28 to 61 cm), but fluctuates widely from year to year. Average annual temperatures are 45° F in much of the region, but they range from 40° F in the north to 60° F in the south. The freeze-free season ranges from 100 days in the north to 200 days in the south.

"Mollisols are dominant over much of the region, but Ustic Aridisols are important in the west. Shallow Entisols on the more sloping parts of the dissected areas, sand Entisols in sandy areas, and Fluvents on flood plains are also extensive. Less extensive, but locally important, are the clayey Vertisols and sodic Aridisols in depressions and terraces.

"A large part of the region is in range; some wheat is produced by dry farming methods, mainly along the eastern margin. Irrigation agriculture is practiced along some of the major rivers. Forage and grain for livestock are the principal crops on irrigated land; potatoes, sugar beets, and vegetable crops are important locally."

Northern Rolling High Plains - Sub-Region

"Land Use: More than four-fifths of the land is in ranches, most of the remainder is owned by the Federal Government. Nearly three-fourths of the area is in native grasses and shrubs grazed by cattle and sheep. Gently sloping deep soils amounting to 4 or 5 percent of the area, are dry farmed to wheat. Narrow strips of land along the Yellowstone River and one or two of its tributaries are irrigated. Sugar beets, potatoes, vegetables, alfalfa, other hay crops, and feed grains are the principal crops; some of the land is in tame pasture. The upper slopes and tops of some of the higher buttes are in open woodland of western red cedar.

"Elevation and Topography: 3,000 to 6,000 feet (914 to 1829 m) rising gradually from east to west and from north to south. This dissected plain is underlain by shales and sandstones. Slopes are mostly rolling to steep, and wide belts of steeply sloping badlands border a few of the larger river valleys. Local relief is mainly in several tens to a few hundreds of feet. In places, flat-topped steep-sided buttes rise sharply above the general level of the plain.

"Climate: Average annual precipitation of the sub-region is 12 to 16 inches (30 to 41 cm), fluctuating widely from year to year; highest in spring and early autumn; winter precipitation is snow. Average annual temperature - 40° to 45° F. Average freeze-free period - 120 to 140 days.

"Water: The low and erratic rainfall is the principal source of water for agriculture. Water for livestock is stored in small reservoirs but supplies are too small for any significant amount of irrigation. Irrigation water in quantity is available only along the Yellowstone River and one or two of its larger tributaries. Ground water is scarce in most of the area, but locally, sand and gravel deposits and coal beds yield small to moderate amounts.

"Soil: Shallow Entisols such as Bainville, Midway, and Flasher, are major soils in much of the area. Mollisols like Morton, Chama, Vebar, and Regent, in the east; and Aridisols such as Cushman, Renohill, and Terry, in the west, are on the smoother upland slopes. Locally conspicuous, but of small total extent are the cold Alfisols on the higher butte tops and cold sodic Mollisols and sodic Aridisols on nearly level to gently sloping areas. Fluvents like Havre, Lohmiller, and Banks in narrow bands along the major rivers are extensively farmed in many places. About one-eighth of the area consists of rough mountainous areas of extensively eroded badland and other miscellaneous areas with little or no soil cover."

The above description is by design a very broad characterization of a 66,000 mi^2 (171,000 km^2) area. It should be remembered that the study area is approximately 35 mi^2 (91 km^2) in size. The report that follows has considerably more detail than that reported in Handbook 296. Generally, the site-specific information falls within the ranges of the broad characterization.

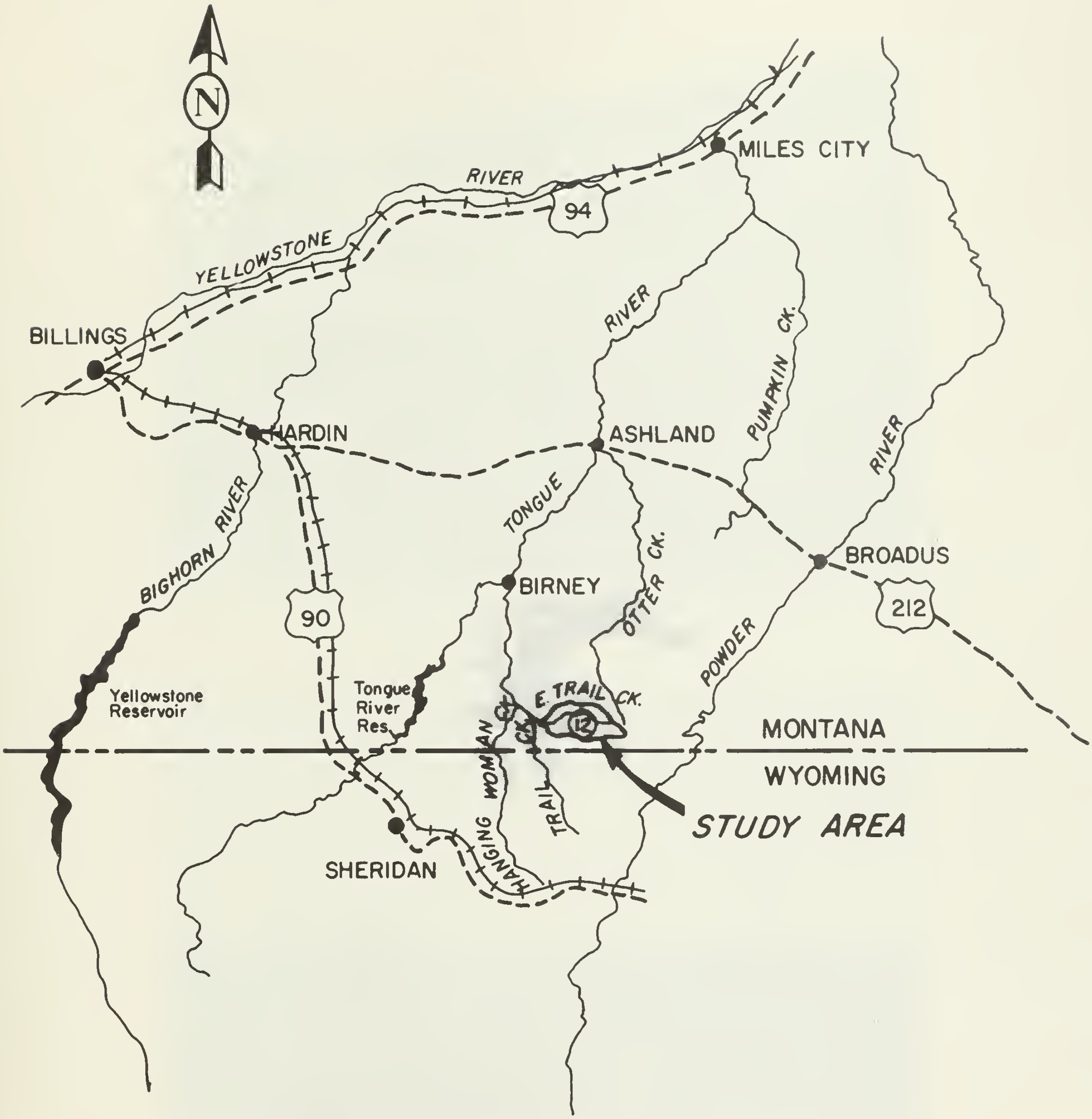
Hanging Woman Creek Study Area

The Hanging Woman Creek study area lies approximately 40 miles (64 km) south of Ashland, Montana, 30 miles (48 km) northeast of Sheridan, Wyoming, and about 4 miles (6 km) north of the Montana/Wyoming boundary. More specifically, the study area under consideration is the East Trail Creek drainage in southeastern Big Horn and southwestern Powder River Counties.

The area is comprised of 21,960 acres (8894 ha), all or in parts of

T8S, R43E, Sections 35, 36
T9S, R43E, Sections 1, 2, 11, 12
T8S, R44E, Sections 26, 27, 28, 29, 31, 32, 33, 34, 35, 36
T9S, R44E, Sections 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 21, 22, 23, 24
T9S, R45E, Sections 6, 7, 8, 17, 18, 19, 20, 21, 28, 29

The study area (EMRIA Study No. 12) is shown relative to major landmarks in Figure 1. Figures 2 through 6 are photographs taken in the study area and illustrate the terrain of the subject study.



(12) Hanging Woman Creek Study Area

Hanging Woman Creek Coal Field

Figure 1. General Location Map of the Hanging Woman Creek Study Area.

Figure 2 - Trail Creek flood plain, Hanging Woman Creek study area, Montana.

Figure 3 - Vegetation on Hanging Woman Creek study area; perennial grasses and big sage.

Figure 4 - Vegetation on Hanging Woman Creek study area; predominantly silver sage and big sage.

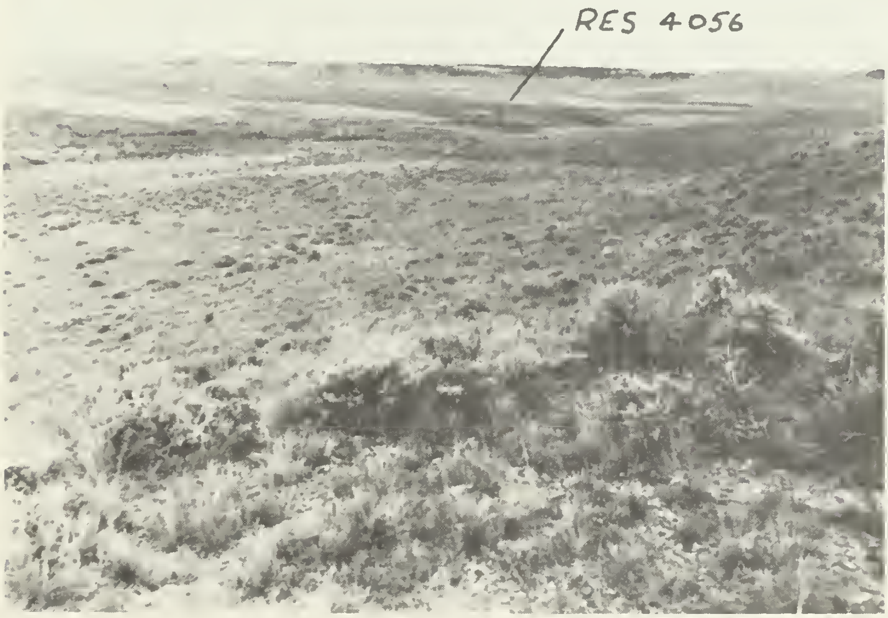


Figure 5 - Reservoir #4056, T9S, R44E, Section 6, with associated vegetation.

Figure 6 - Stream gaging station #06307560 on East Trail Creek, Montana.

Historical Development

Hanging Woman Creek and its tributary, East Trail Creek, are rich in Indianlore. This was Plains Indian country which supported their mode of living. In bitterly fought battles, the Indians lost these lands and consequently were forced onto reservations, namely Crow and Northern Cheyenne. Battles of note in the surrounding areas were, namely, Rosebud Battle, June 17, 1876, now a National Historical Site; Battle of Wolf Mountain (Battle of the Butte), January 8, 1877; and the Battle of Hanging Woman Creek, January 7, 1877.

The open range cattle industry brought development to the area in the early 1880's when the vast trail herds began arriving from Texas and Oregon.

The Niobara Cattle Company of Nebraska stocked the OW Ranch with Oregon cattle on Hanging Woman Creek in the mid-1880's. The OW Ranch is now the Kendrick Cattle Company with surface ownership extending over much of the East Trail Creek drainage. Other surface ownerships in East Trail Creek are Mibra Lloyd and C. F. Conley.

A fourth-class post office was established at Quietus in 1919 and ceased operations in 1960. The post office building stands to this date in a sad state of disrepair. Towns that developed in the area are Ashland and Broadus, Montana and Sheridan, Wyoming.

Strip mining of sub-bituminous coal near Colstrip, Montana, has taken place intermittently since 1923. Through 1958, coal in the area was mined by Northwest Mining Company, a subsidiary of the Northern Pacific Railway (now Burlington Northern, Inc.) for use in coal-fired steam locomotives. Mining was discontinued when the steam locomotives were replaced by the diesel-electric engines. In 1959, the mine, equipment, and the town of Colstrip were sold to The Montana Power Comapny (MPC). Mining was resumed in 1968 by Western Energy Company (WEC), a subsidiary of MPC. From 1969 through 1977, WEC's Rosebud mine produced a cumulative total of 45.8 million tons. Reserve estimates in 1974 ranged from 850 million to 1 billion tons for WEC leases in the Colstrip coal field. Projected yearly production for the Rosebud mine will be 18 million tons by 1980.

The Decker West strip mine is one of the most prolific producers of coal in North America, and delineated reserves (3.1 billion tons according to Matson and Blumer, 1973) make the Decker area the most important coal district in Montana. Production began at West Decker in 1972 with an output of 800,000 tons from the Anderson-Dietz No. 1 combination coal seam, and by 1977 cumulative production had amounted to 42 million tons.

Decker West is owned by Decker Coal Company, and the mine is operated jointly by Peter Kiewit Sons and Pacific Power and Light, each with a one-half interest. A Decker East mine began production in the spring of 1978. Decker West and East mines are located within the Decker and Deer Creek coal deposits, respectively. A Decker North mine is scheduled to open in the near future north of the Decker mine. Strippable reserves at the Deer Creek deposit are 410 million tons; those of the Decker deposit, 2.24 billion tons (Matson and Blumer, 1973).

Present Land Use

Agriculture within the study area is confined to cattle grazing with some native hay harvested along flat bottomed drainages. Along the road which extends south and east of Quietus, which is in the extreme easterly extent of the Upper East Trail Creek drainage, are several hay meadows. These are primarily in Section 35, T8S, R44E; Sections 1, 2, 12, T9S, R44E; and Section 7, T9S, R45E. There are a few small irrigated hay fields.

Commercial timber production, except for corral posts and some fuel wood, does not exist.

Grain production is not a factor. There are no commercial gravel pits in the area.

The following Table No. 1, extracted in portion from Land Planning and Classification Report of the Public Domain Lands in the Tongue River Area, indicates the principal suitability of the land to be grazing wildlife and watershed.

Table 1 presents data on isolated tracts of the study area, but is representative of a large part of the watershed. The land capability classification was adapted from Soil Conservation Service standards. As illustrated in Table 1, only 2 land classes are found in the study area. Land Class VI is characterized as suitable for range and woodland. Slopes range from 0 to 20% and the surface is irregular to rough or rocky. Some pertinent soil characteristics are negligible to moderate relative salinity, fair to good fertility, light to moderate productivity, and moderate susceptibility to erosion.

Land Class VII is suitable for range and woodland with severe restrictions. The surface can be rough, rocky or eroded on 0 to 100% slopes. There can be a critical relative salinity problem. Fertility is poor and productivity is poor to light. The land class is highly susceptible to erosion.

Surface ownership is primarily private with isolated tracts of federal and state lands (Figure 7). With the exception of approximately 1 1/2 mi^2 (4 km^2), coal ownership lies with the Federal Government (Figure 8).

Future Development

The Montana State Director of the Bureau of Land Management has released the proposed federal leasing action for the Powder River area. This area includes the Hanging Woman Creek coal field as defined by Matson and Blumer (1973), which in turn includes the Hanging Woman Creek study area (see Figure 1 for locations).

The proposed leasing areas are subdivided into levels according to priority and planned lease dates. Level 1 and 2 lease tracts are scheduled to be leased prior to 1990. Level 3 tracts, which includes the Hanging Woman Creek coal field, are not being proposed for lease at this time.

Table 1 -- Description, classification, suitablilty and proposed management of the public domain, by township and range, within the Isolated Tract Classification areas of the Tongue River Area, Montana and Wyoming.

MONTANA PRINCIPAL MERIDIAN

Big Horn County

Twp. South	Range East	Sec.	Subdivision	Acres	General Land Character	AUM's	Present Land Use	Land Capability Classification	Principal Suitability	Proposed Management
8	44	27	E½SW¼	80	Mod. sloping grassland	16	1-6	VI	1-6	Private
8	44	27	E½SE¼	80	Mod. sloping grassland	16	1-6	VI	1-6	Private
8	44	31	Lots 5,6,15,16	78.20	Gentle to strongly sloping grassland	19	1-4-6	VI/20:VII/49	1-4-6	Private
8	44	34	NE¼NE¼	40	Mod. Sloping grassland	8	1-6	VI	1-6	Private
9	44	2	W½NE¼	80	Mod. rolling grassland	20	1-6	VI	1-6	Private
9	44	2	NE¼SE¼	40	Mod. sloping grassland	7	1-6	VII	1-6	Private
9	44	6	Lots 1,2,8,9,10,11,12, 13,14,15,16,17,18; E½SE¼	560.02	Gently rolling grassland	193	1-4-6	VI	1-4-6	Public
9	44	7	Lots 6,15,16	60.97	Gently rolling grassland	16	1-6	VI	1-6	Public
9	44	7	Lots 19,20,S½SE¼	160	Mod. rolling grassland	42	1-4-6	VI	1-4-6	Public
9	44	8	SW¼	160	Gentle to mod. rolling grassland	53	1-4-6	VI	1-4-6	Public
9	44	9	S½SE¼	80	Gently rolling grassland	12	1-6	VI	1-6	Public
9	44	11	E½SW¼	80	Mod. rolling grassland	13	1-6	VI	1-6	Private
9	44	15	SW¼	160	Mod. rolling grassland	27	1-6	VI	1-6	Public
9	44	18	NE¼NE¼	40	Mod. rolling grassland	11	1-4-6	VI	1-4-6	Public
9	44	19	Lot 15	21.03	Gently rolling grassland	3	1-6	VI	1-6	Public

Note: The material in the above table is self-explanatory with the exception of the numbers in the columns "Present Land Use" and "Principal Suitability". The numerals which denote this land use and suitability are: 1. Grazing: 2. Cropland: 3. Recreation: 4. Wildlife: 5. Mining: 6. Watershed: 7. Timber: 8. Human Occupancy and Industrial Development: 9. Access and Preservation of Public Values: 10. Submerged. "PSW" identifies a Power Site Withdrawal; "SDW" a Stock Driveway Withdrawal; "Rec" a Recreation Site Withdrawal; and "PWR" a Public Water Withdrawal.

Taken from Land Planning and Classification Report of the public domain lands in the Tongue River Area, Montana and Wyoming, A Missouri River Basin Investigation, BLM, Denver, Colorado, November 1967.

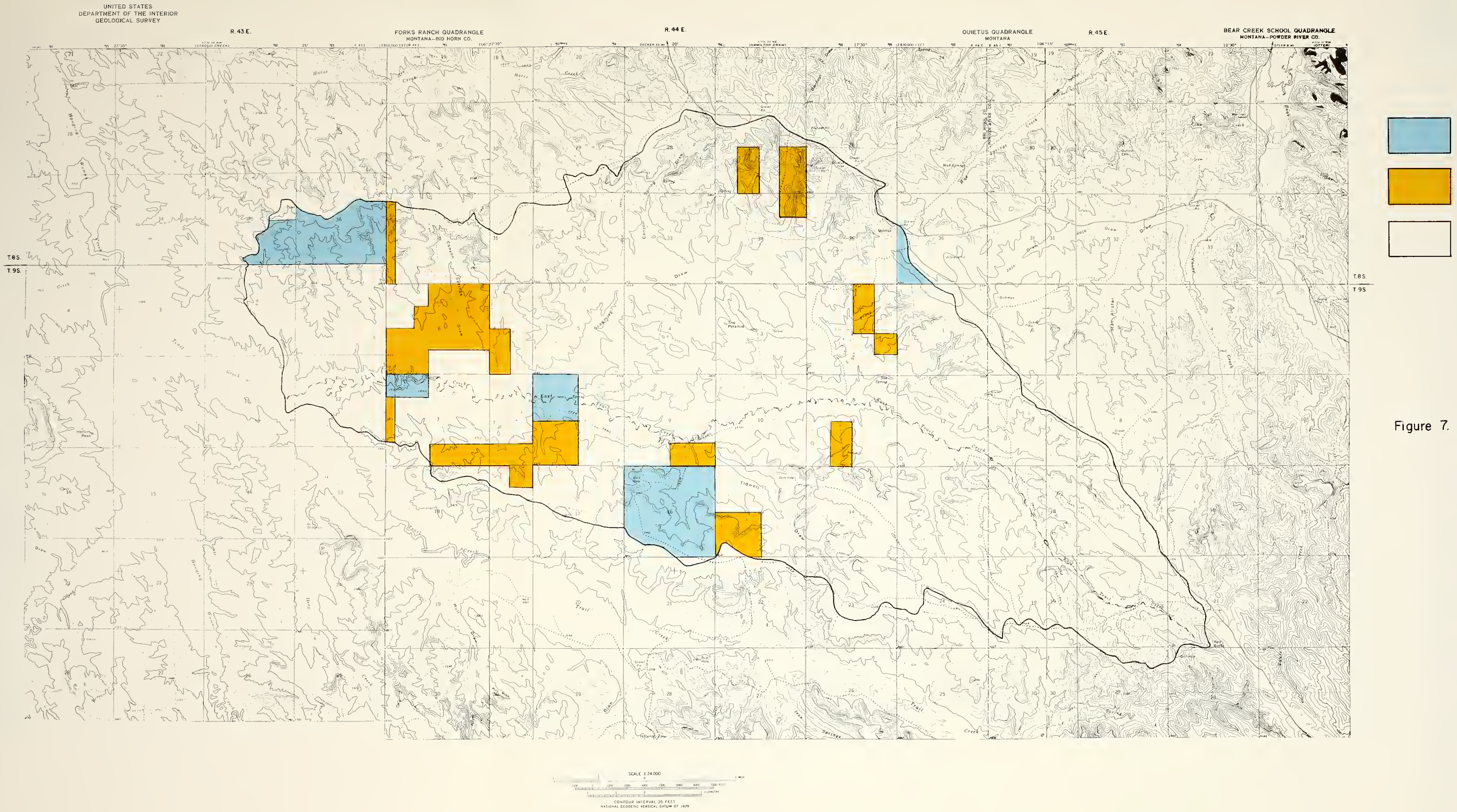


Figure 7. Surface Ownership of Hanging Woman Creek Study Area.

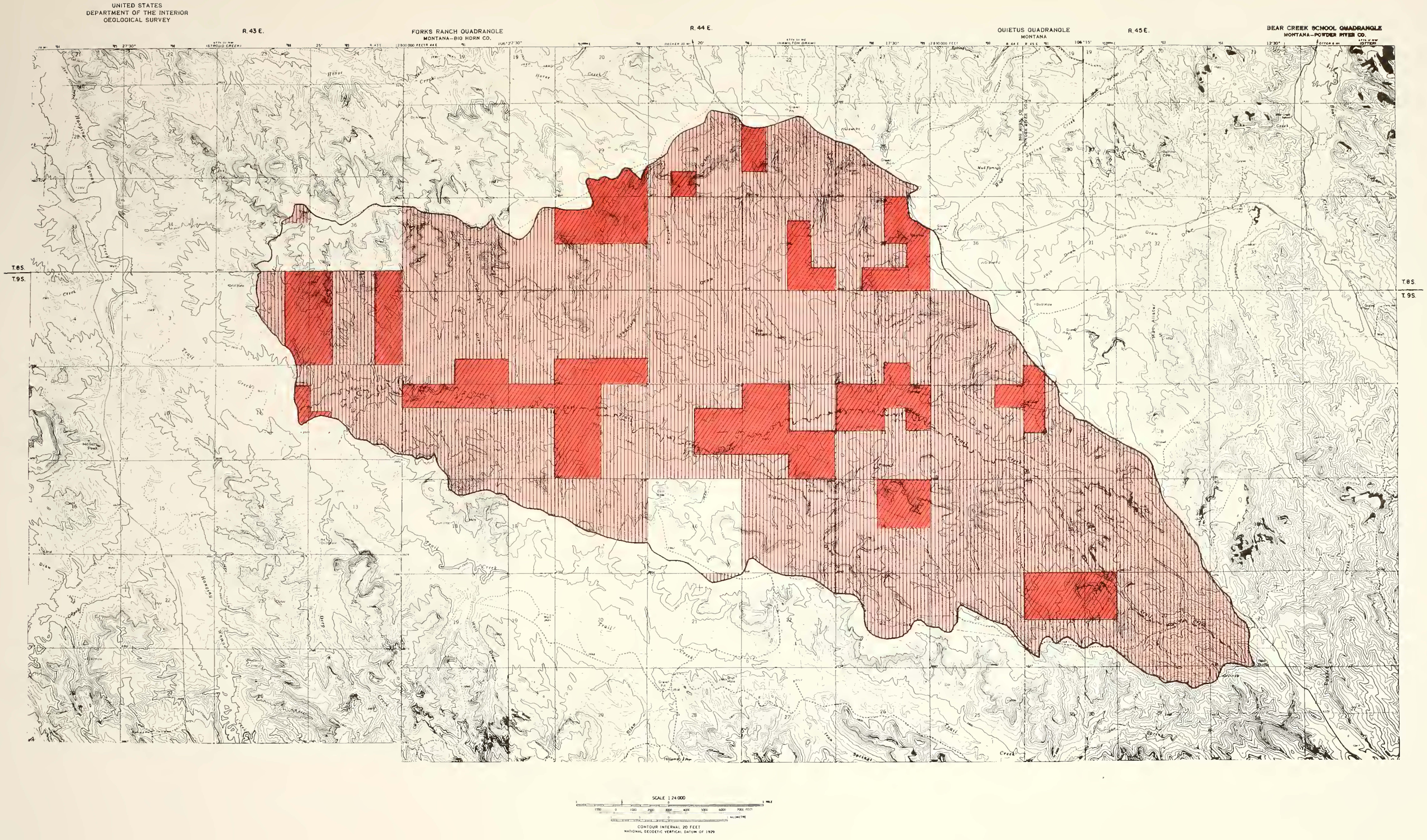


Figure 8. Federally Owned Minerals at Hanging Woman Creek Study Area.

Hanging Woman Creek Coal Field

About 30,000 acres (12,150 ha) of the Hanging Woman Creek coal field is underlain by strippable coal of sub-bituminous C rank, principally in the Anderson and Dietz coal beds. Additional small areas are underlain by strippable deposits of coal in the Canyon, Smith, and Roland coal beds, but these deposits are so small compared with those of the Anderson and Dietz that they should not alter the economic potential of the Hanging Woman Creek coal field significantly.

Coal Resource Occurrence maps showing coal thickness, overburden, structure and resources of each major coal bed in this area are presently being prepared by the U.S. Geological Survey and will be published in the near future.

The most important bed is the Anderson coal bed which is 15 to 36 feet (4 to 11 m) thick and is essentially free of partings. Although much of it has burned, resulting in large masses of baked and fused rock called clinker, large areas of unburned coal still remain at shallow depth. These deposits are strippable in and adjacent to the major tributaries of Hanging Woman Creek.

The Dietz coal bed is generally 50 to 70 feet (15 to 21 m) below the Anderson coal bed but is locally as much as 120 feet (37 m). In most of the Hanging Woman Creek coal field, it is 7 to 18 feet (2.1 to 5.5 m) thick, generally thickening northward. In the southwestern one third of the area it splits into 2 to 4 beds ranging from 3 to 5 feet (1 to 1.5 m) thick, and therefore has little economic potential. The Dietz coal bed is probably strippable in and adjacent to the major tributaries on the east side of Hanging Woman Creek.

Transportation

The Hanging Woman Creek coal field lies about 40 miles (64 km) southwest of U.S. Highway 212. A secondary gravel road provides access into the coal area. The nearest railspur located at Colstrip is about 65 miles (105 km) to the northwest along a potential rail route. A private railspur lies 30 miles (49 km) southwest of the coal area via the Tongue River Valley.

CLIMATE

The Hanging Woman study area is influenced primarily by continental climate and convective thunderstorms in the summer. The study area lies within the Tongue River Basin and ranges in elevation from 3560 feet (1085 m) MSL at the mouth to 4200 feet (1280 m) MSL at the highest point in the watershed. Otter 9SSW weather station is located approximately 1 1/2 miles (2 km) NE of the watershed in the NE 1/4, Section 31, T8S, R45E, at an elevation of 4100 feet (1250 m) MSL. Due to the similarity of terrain, this station was used to characterize the climate of the study area. The period of record available is 1961 through 1976. Table 45 in the appendix presents these data.

The watershed lies almost in the center of the Northern Rolling High Plains sub-region which reports on annual average precipitation of 12 to 16 inches (30 to 41 cm). The mean annual precipitation at Otter 9SSW is 19.45 inches (49 cm). The weather station lies at a relatively higher elevation than most of the watershed and probably exhibits the results of some orographic effects. The lower end of the watershed may fall within the 12-16 inch (30 to 41 cm) range reported by Handbook 296. The same can be said about temperatures reported from Otter 9SSW versus the broad averages in Handbook 296.

Temperature averages and extremes are illustrated in Figure 9. Mean monthly minimums are greater than 32° F in May through October. Mean monthly lows are greater than 32° F during June, July and August. There is a .2 day in June, however, with an average minimum temperature less than 32° F (see Figure 10).

Mean monthly precipitation is presented in histogram form in Figure 11. Cumulative precipitation as a percent of mean annual precipitation is also presented in Figure 11. These data suggest a relatively wet spring with April, May and June receiving 8.87 inches (23 cm) or 46% of the annual precipitation. The rest of the year is relatively uniform at about 1 inch (2.54 cm) per month.

Snow occurs every month of the year except June, July and August. Snow begins to accumulate in late September and persists until May. The greatest accumulation occurs in January and February (see Figure 12). The average snow depth in January is almost 9 inches (23 cm) and in February slightly more than 7 inches (18 cm). This figure represents the top of the watershed, suggesting that the lower part of the watershed and protected areas are not snow covered throughout the year except during heavy snow seasons. Selected storm frequencies and duration are presented in Table 2.

There are no evaporation data near the site. The only evaporation data in the Miles City District are located at Fort Peck, Sidney and Terry with mean annual precipitation of 11.84, 13.67, and 11.37 inches (30, 35, and 29 cm), respectively. Potential annual evaporation at these sites is 50.49, 35.55, and 41.89 inches (128, 90, and 106 cm), respectively. This suggests that

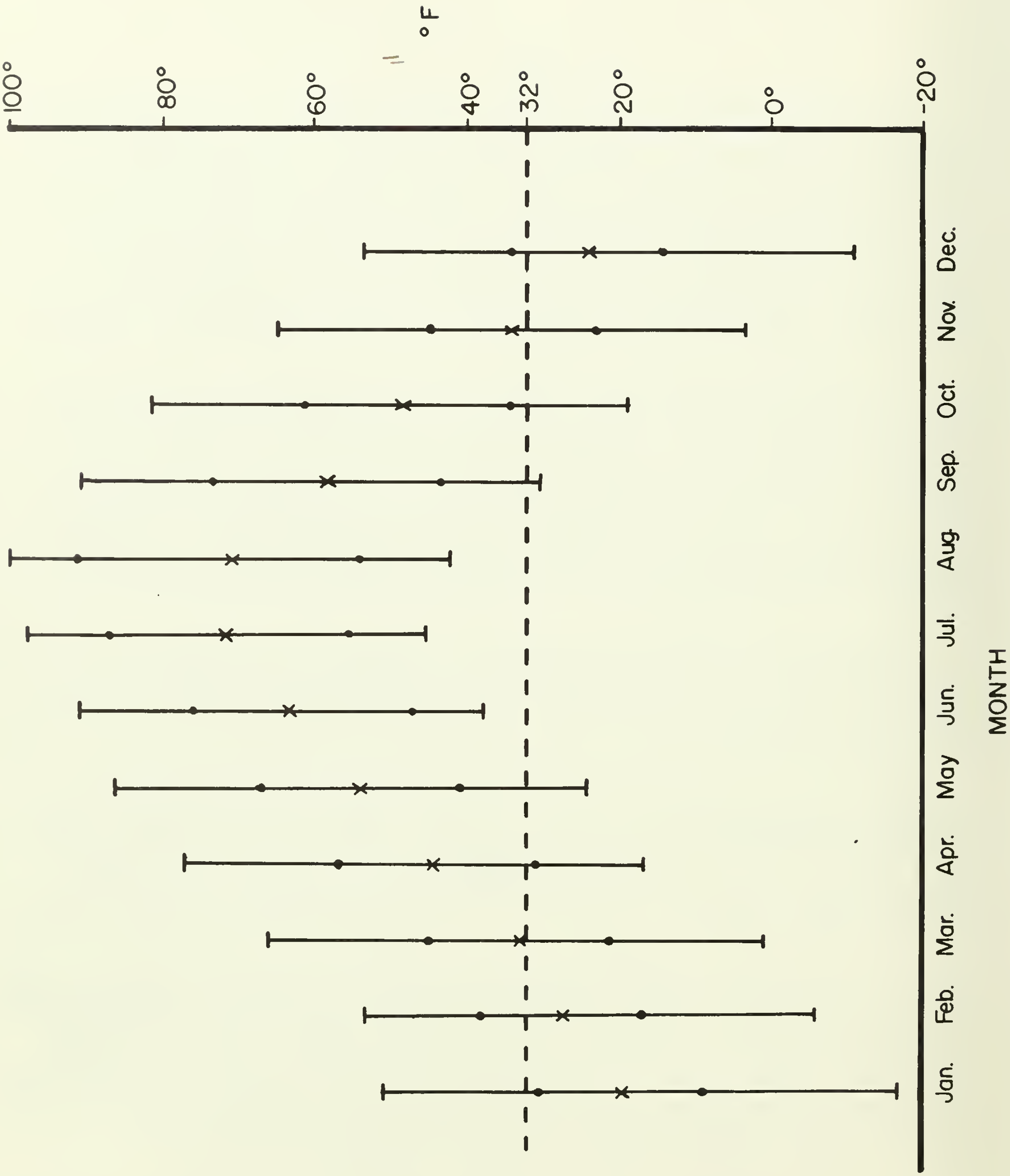


Figure 9. Mean Monthly Extremes, Mean Monthly Minimums and Maximums, Mean Monthly Temperatures at Otter 9-SSW, 1961 - 1976.

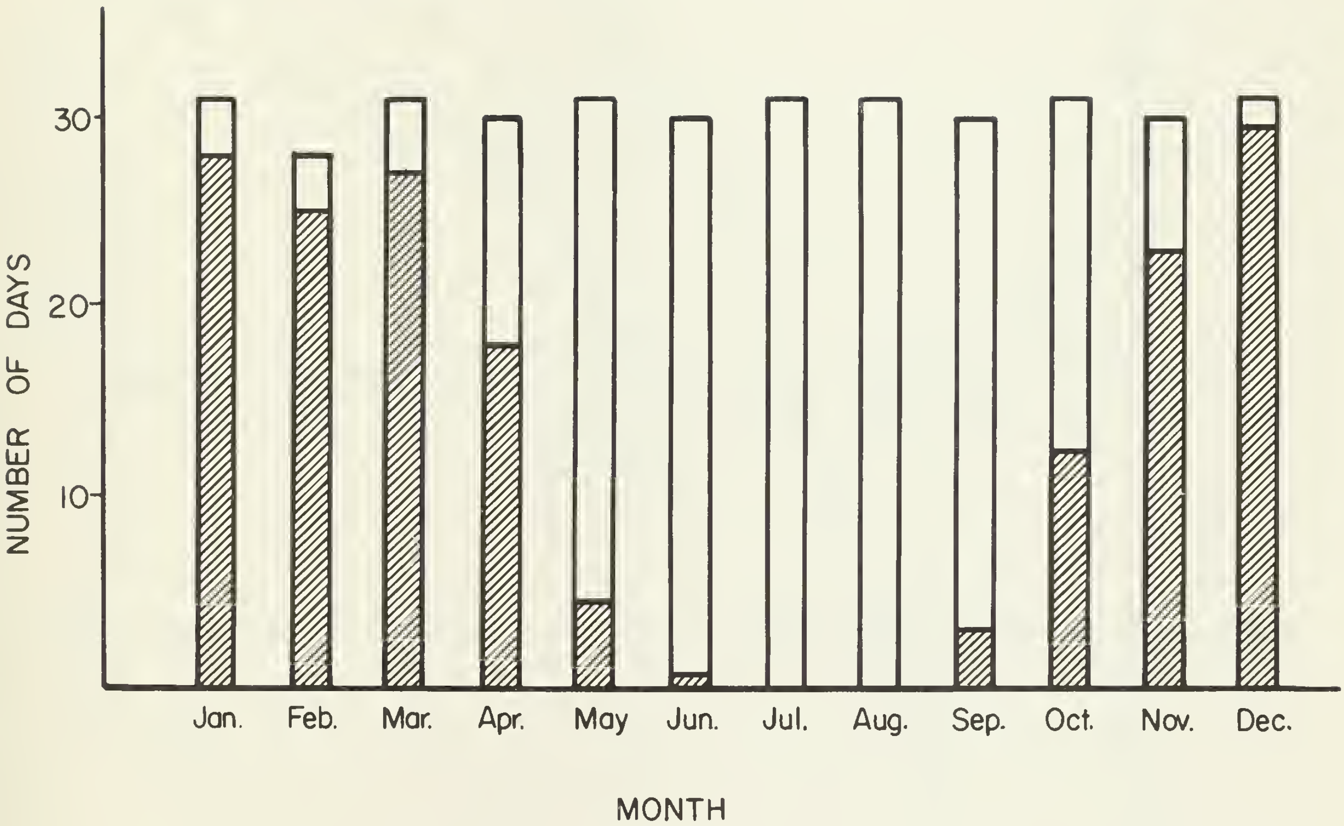


Figure 10. Number of Days/Month Mean Minimum Temperature Is Less Than 32°F Compared to Total Days in Month.

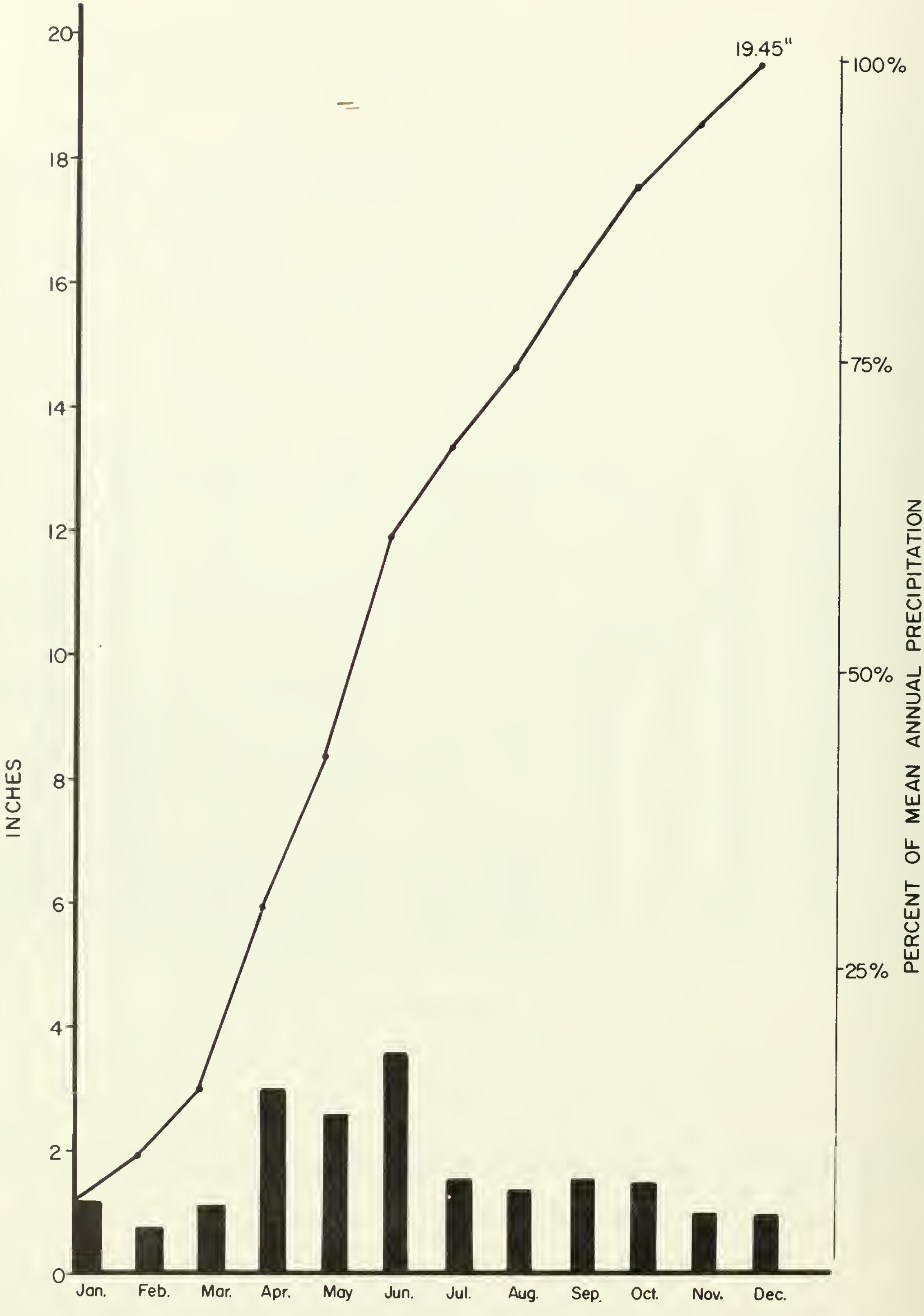


Figure 11. Mean Monthly and Mean Cumulative Precipitation for Otter 9-SSW 1961-1976

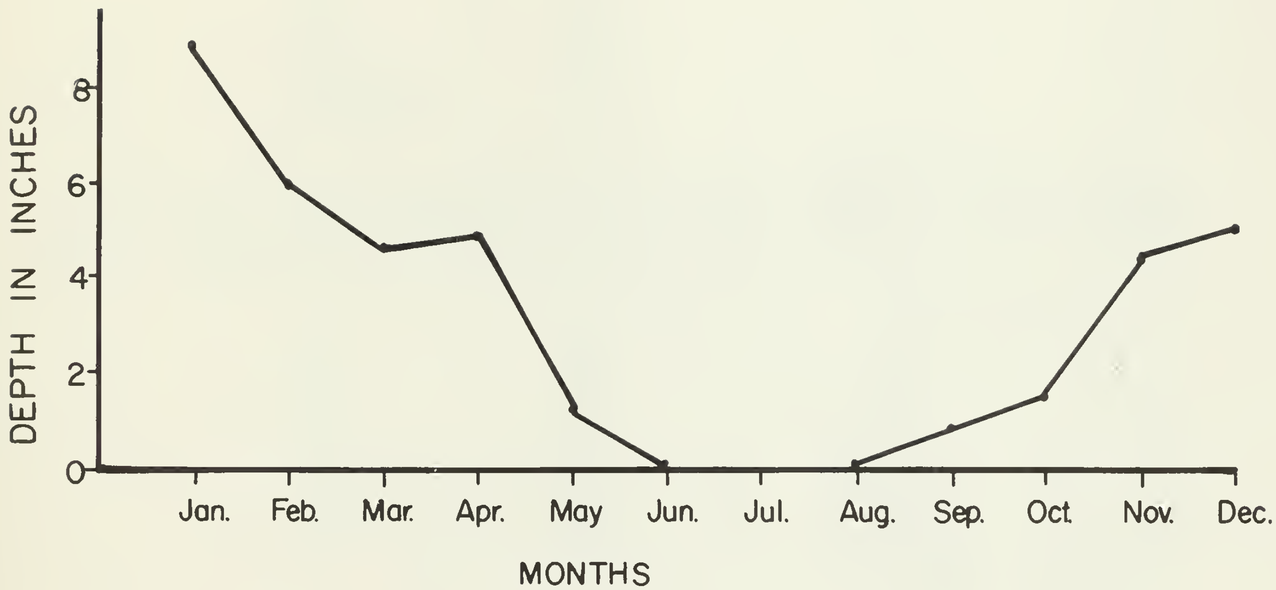


Figure 12. Average Greatest Snow Depth at Otter 9-SSW, 4100 MSL, 1961 - 1976.

Table 2. Estimated Precipitation Amounts for Selected Storm Frequency and Duration for Big Horn County.

(From the U.S. Weather Bureau, Technical Paper No. 40)

	Frequency of once in--				
Duration	2 years Inches	5 years Inches	10 years Inches	25 years Inches	50 years Inches
30 minutes...	0.5	0.7	0.9	1.0	1.2
1 hour.......	0.6	0.9	1.1	1.3	1.5
3 hours......	0.9	1.3	1.5	1.8	2.0
6 hours......	1.2	1.5	1.8	2.1	2.5
12 hours.....	1.4	1.8	2.2	2.6	2.9
24 hours.....	1.5	2.2	2.5	3.0	3.4

potential evapotranspiration (PET) would exceed available moisture from precipitation during the growing season. The average percentage of total evaporation that occurs each month at the three stations is as follows:

April	7%
May	15%
June	18%
July	23%
August	21%
September	12%
October	4%

Caprio (1973) has estimated average annual PET for Montana. The Hanging Woman Creek study area lies within the estimated 26 inch (66 cm) zone. If the above percentages are applied to this value, then estimated PET by month for the study area is as follows:

April	1.82 inches	4.62 centimeters
May	3.90	9.91
June	4.68	11.89
July	5.98	15.19
August	5.46	13.87
September	3.12	7.92
October	1.04	2.64
Total	26.00 inches	66.04 centimeters

Figure 13 compares the estimated monthly PET with mean monthly precipitation at Otter 9SSW. There are at least four obvious sources of error in this analysis:

1. The average monthly percentage of annual evaporation at the three stations may not be representative of the study area.
2. The average monthly percentage of annual evaporation may not describe the average monthly percentage of annual PET.
3. The PET is an estimate that may not be applicable to vegetation used in reclamation of the site.
4. The precipitation values are from one station and do not represent area distribution of precipitation over the entire watershed.

Figure 13, does serve to illustrate, however, the moisture stress plants may experience in July, August and September if precipitation is the only source of water.

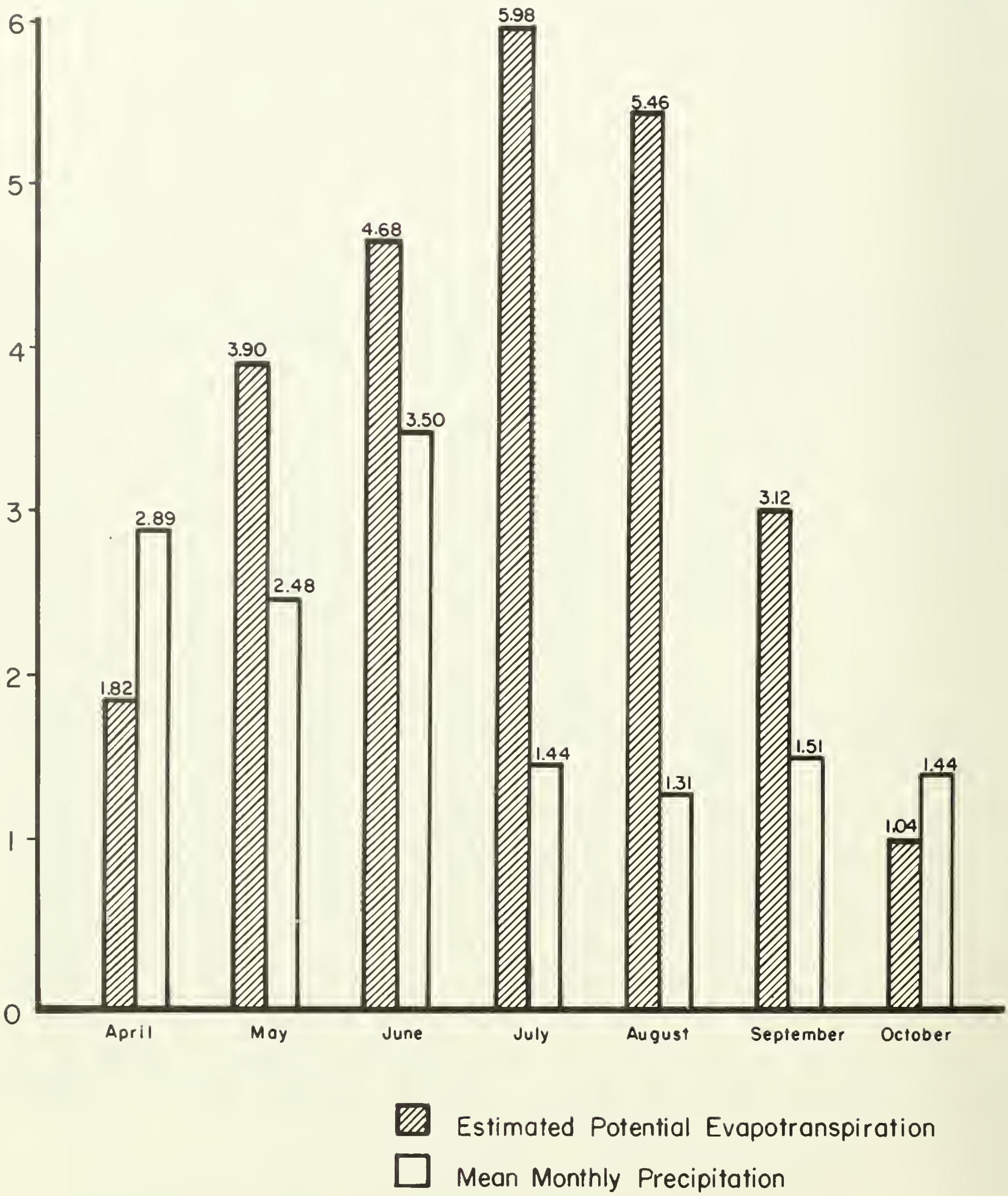


Figure 13. Mean Monthly Estimated Potential Evapotranspiration Compared to Mean Monthly Precipitation for Study Area.

PHYSIOGRAPHY

The Hanging Woman Creek study area is the East Trail Creek watershed. As illustrated in Figure 1, East Trail Creek is tributary to Trail Creek which in turn is tributary to Hanging Woman Creek which flows into the Tongue River at Birney. This area is in the Missouri Plateau section of the Great Plains physiographic province. Generally, this province is characterized by a series of benches which progress up to flat topped narrow divides between major stream valleys. These flat topped ridges constitute the remains of a once more widely extended plateau surface, which have been intricately dissected to create steep slopes adjacent to stream valleys.

The relief in the study area is approximately 600 feet (183 m), ranging from 3560 foot (1085 m) elevations along Hanging Woman and East Trail Creeks to 4200 foot (1280 m) elevations in the uplands along both creeks.

The ridges are remnants of an old upland surface that has been dissected leaving the margins of the uplands delineated by the outcrops of resistant sandstone ledges. The flat top ridges are generally protected by clinker zones created by burning coal seams.

The valley sides are characterized by gentle to moderately steep slopes, with smooth, coalescing alluvial fans, footslopes, and stream terraces. East Trail Creek is entrenched to a depth of 6 1/2 to 16 feet (2 to 5 m) into alluvial materials derived from soft, sedimentary rocks.

The lithology of the surrounding area comprises sandstones, mudstones, and shales within the Tongue River Member of the Fort Union Formation and limited outcrop of the Wasatch Formation, both of Tertiary age. There is a limited area of clinker outcrop near the west end of the study area.

Stream gradients are relatively steep with the dominant stream pattern being dendritic.

Figure 7 illustrates the dendritic nature of the stream pattern. The landform of the area can be seen in the topography illustrated in Figure 7, and the aerial photograph (Figure 14).

Figure 14. Aerial Photograph of the Hanging Woman Creek Study Area

GEOLOGY AND COAL RESOURCES

of the

Hanging Woman Creek Study Area

Big Horn and Powder River Counties, Montana

The area was mapped geologically in 1976 by W. C. Culbertson and M. C. Klett as part of their geologic investigation of the Forks Ranch and Quietus 7 1/2 minute topographic quadrangles. A report of the geology and coal resources of these two quandrangles is in preparation. Five holes were cored in and near the study area by the Montana Bureau of Mines and Geology. The coal beds from these cores were sampled and submitted for analysis by J. R. Hatch. The results of these analyses were analyzed statistically by J. R. Hatch and R. H. Affolter.

Geologic Setting

The coal-bearing rocks underlying the Hanging Woman Creek study area comprise all of the Tongue River Member of the Fort Union Formation of Paleocene age, and the lower part of the overlying Wasatch Formation of Eocene age (Figure 15). The contact between the two formations is placed at the top of the Roland coal bed of Baker (1929). The stream bottoms of Trail Creek and East Trail Creek are underlain by alluvium that is made up of sand, silt, clay, and some gravel.

The coal-bearing rocks are as much as 2,300 feet (700 m) thick and contain about 20 beds of coal, of which five are 10 or more feet (3 m) in thickness. The rocks between the coal beds consist of sandstone, siltstone, shale, and carbonaceous shale. The beds of sandstones and siltstones are generally poorly cemented, but locally some are well cemented or grade into limestones that form resistant ledges or benches. At the western end of the study area, the Anderson coal has burned back from the outcrop, and the resulting heat has baked and fused the overlying rocks. The baked rock, called clinker, is a brittle resistant reddish rock that is as much as 100 feet (30 m) thick along Hanging Woman Creek to the west.

The target coal bed for this investigation was the Anderson coal bed, which is 26 to 33 feet (7.9 to 10.1 m) thick in this area (Figure 16). In addition, the Dietz coal bed, which is 9 to 12 feet (2.7 to 3.7 m) thick, may be recoverable because it is 50 to 100 feet (15 to 30 m) below the Anderson bed (Figure 17). Several drill holes in and near this area show that the Canyon coal bed is 15 to 21 feet (4.6 to 6.4 m) thick and is 180 to 250 feet (55 to 75 m) below the Anderson bed. Because it is considered to be too deep for surface mining, it was not investigated further. The coal

Figure 15. - Geologic map of the Hanging Woman Creek Study Area.

EXPLANATION

U/D Fault dotted where concealed. U, upthrown side, D, down thrown side.

•B Drill hole with data on Anderson coal bed.

—30— Isopach of thickness of Anderson coal bed, in feet. Contour interval is 2 feet.

—3660— Structure contour on top of Anderson coal bed, in feet above mean sea level. Contour interval is 20 feet.

Area where overburden is less than 100 feet thick.

Area where overburden is 100 to 200 feet thick.

Boundary of area where Anderson bed has burned.

Boundary of area where coal probably is missing because of stream erosion.

Note 1 foot = 0.3 meter.

Base from U.S. Geological Survey, 1972

Figure 16. - Coal thickness, overburden thickness, and structure of Anderson coal bed in Hanging Woman Creek Study Area.

Figure 17. - Coal thickness, overburden thickness, and distance below Anderson coal bed, of the Dietz coal bed in Hanging Woman Creek Study Area.

beds above the Anderson coal bed (Figure 18) are in general thin, or of poor quality, or of limited extent.

The coal-bearing strata are nearly flat-lying except in the vicinity of the three northeast-trending normal faults. The largest fault, which trends through the middle of the mapped area has displaced the rocks on the south side downward as much as 260 feet (80 m). As a result, the Anderson coal bed southeast of the fault is so deep that only a narrow strip adjacent to the creek bottom is under less than 200 feet (61 m) of overburden (Figure 16).

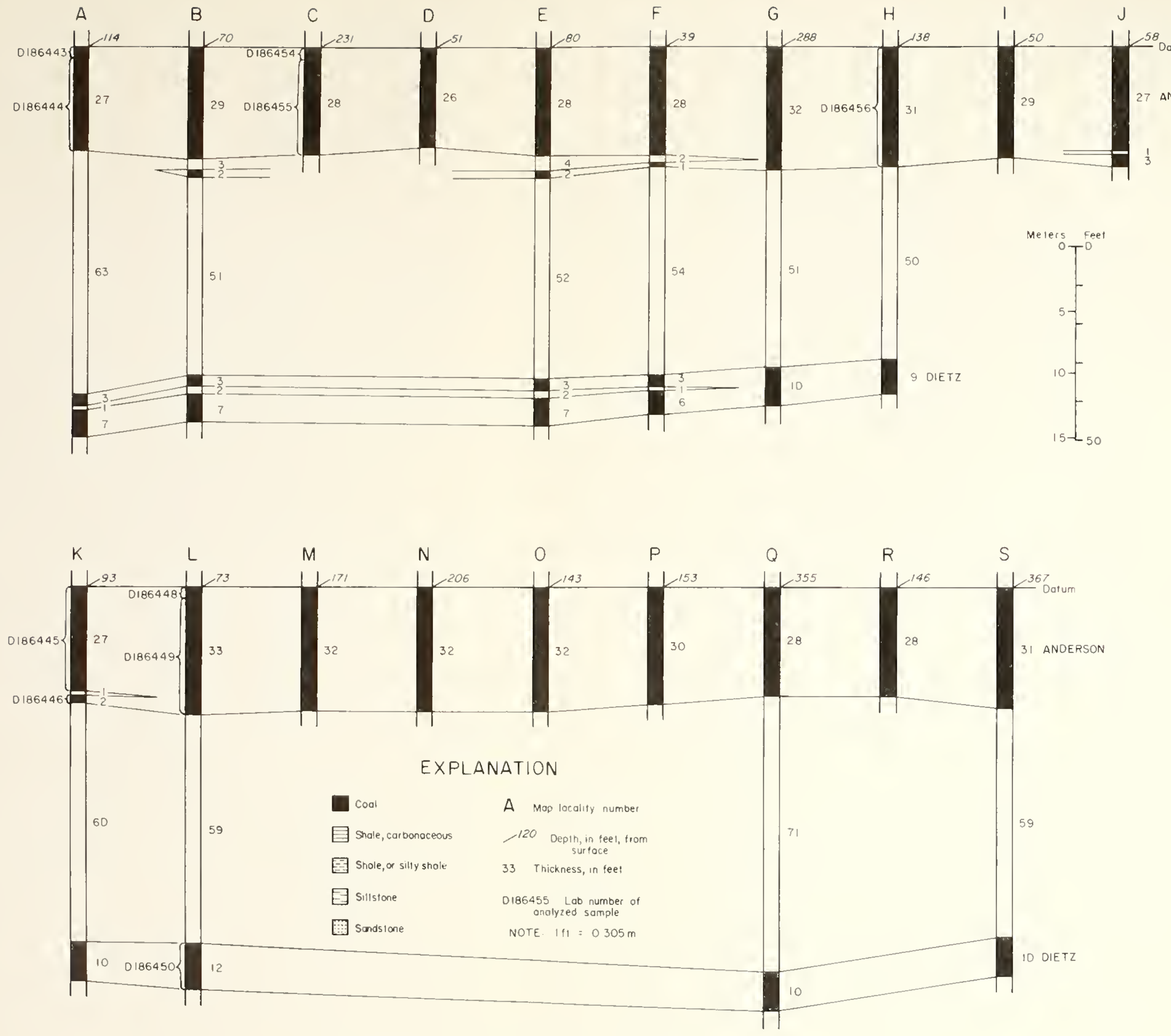
COAL

Origin

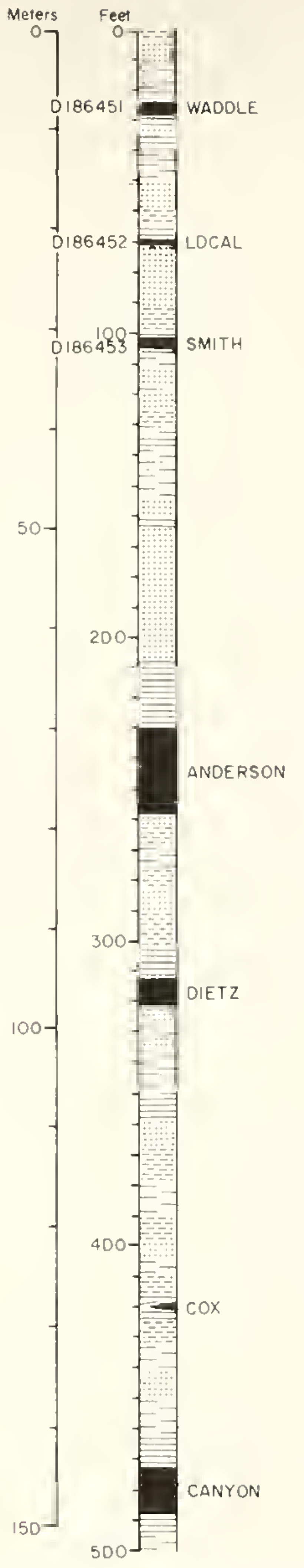
Coal has been defined as "a readily combustible rock containing more than 50 percent by weight and more than 70 percent by volume of carbonaceous material, formed from compaction or induration of variously altered plant remains similar to those of peaty deposits. Differences in the kinds of plant materials (type), in degree of metamorphism (rank), and range of impurity (grade), are characteristics of the varieties of coal" (Schopf, 1956). Inherent in the definition is the specification that coal originated as a mixture of plant remains and inorganic mineral matter that accumulated in a manner similar to that in which modern-day peat deposits are formed. The peat then underwent a long, extremely complex process called "coalification," during which diverse physical and chemical changes occurred as the peat changed to coal, and the coal assumed the characteristics by which members of the series are differentiated from each other. The factors that affect the composition of coals have been summarized by Francis (1961, p. 2) as follows:

1. The mode of accumulation and burial of the plant debris forming the deposits.
2. The age of the deposits and their geographical distribution.
3. The structure of the coal-forming plant, particularly details of structure that affect chemical composition or resistance to decay.
4. The chemical composition of the coal-forming debris and its resistance to decay.
5. The nature and intensity of the plant-decaying agencies.
6. The subsequent geological history of the residual products of decay of the plant debris forming the deposits.

For extended discussions of these factors, the reader is referred to such standard works as Moore (1940), Lowry (1945), Tomkeieff (1954), Francis (1961), and Lowry (1963).



(See figure 20 for lithology in cored holes)



Composite columnar section showing relations of Anderson and Dietz beds to coal beds above and below in Fort Union Formation

Map No.	Hole Name and Location	Surface Elevation (in feet)	Cored Interval (in feet)	Geophysical Logs [1/]
A	Mont. Bur. Mines & Geology, HWC-21 NW¼, sec. 2, T. 9 S., R. 43 E.	3665	12-144	Gamma Ray
B	Mont. Bur. Mines & Geology, US 7787 SE¼, sec. 2, T. 9 S., R. 43 E.	3580	--	Gamma Ray, Density
C	Mont. Bur. Mines & Geology, HWC-27 SE¼, sec. 14, T. 9 S., R. 43 E.	3710	11-262	Gamma Ray
D	Mont. Bur. Mines & Geology, HWC-17 NW¼, sec. 13, T. 9 S., R. 43 E.	3606	--	Gamma Ray
E	Mont. Bur. Mines & Geology, US 7788 SE¼, sec. 12, T. 9 S., R. 43 E.	3621	--	Gamma Ray, Density
F	Mont. Bur. Mines & Geology, US 7789 SE¼, sec. 1, T. 9 S., R. 43 E.	3605	--	Gamma Ray, Density
G	Mont. Bur. Mines & Geology, US 7795 NW¼, sec. 31, T. 8 S., R. 44 E.	3842	--	Gamma Ray, Density
H	Mont. Bur. Mines & Geology, HWC-23 & HWC-24 (composite) NW¼, sec. 6, T. 9 S., R. 44 E.	3735	8-172	Gamma Ray
I	Mont. Bur. Mines & Geology, SH-16 NW¼, sec. 7, T. 9 S., R. 44 E.	3611	2/	2/
J	Mont. Bur. Mines & Geology, HWC-29 NW¼, sec. 7, T. 9 S., R. 44 E.	3620	--	Gamma Ray, Density
K	Mont. Bur. Mines & Geology, HWC-20 & HWC-8 (composite) NE¼, sec. 7, T. 9 S., R. 44 E.	3680	8-132	Gamma Ray
L	Mont. Bur. Mines & Geology, HWC-25 NW¼, sec. 8, T. 9 S., R. 44 E.	3670	9-180	Gamma Ray
M	Mont. Bur. Mines & Geology, SH-17 NW¼, sec. 8, T. 9 S., R. 44 E.	3640	2/	2/
N	Mont. Bur. Mines & Geology, HWC-18 NW¼, sec. 8, T. 9 S., R. 44 E.	3680	--	Gamma Ray
O	Mont. Bur. Mines & Geology, HWC-28 SE¼ sec. 32, T. 8 S., R. 44 E.	3738	--	Gamma Ray
P	Mont. Bur. Mines & Geology, HWC-30 SW¼, sec. 9, T. 9 S., R. 44 E.	3700	--	Drillers log
Q	Wolf Exploration Co. 1 State-Mel NW¼, sec. 16, T. 9 S., R. 44 E.	3895	--	Gamma Ray
R	Mont. Bur. Mines & Geology, HWC-19 NE¼, sec. 16, T. 9 S., R. 44 E.	3800	--	Gamma Ray
S	Clark Canadian Exploration Co. 1 Gov't Hawks, NE¼, sec. 15, T. 9 S., R. 44 E.	3983	--	Gamma Ray

1/ Logs used in interpreting thickness of coal beds. Drillers logs are also available for all Montana Bureau of Mines and Geology holes.

2/ Data on these holes from Matson, Blumer, and Wegelin (1973). The Anderson coal bed was cored and analyzed in these holes.

Table of drill hole data

Figure 18 - Coal sections from drill holes; composite columnar section; and drill hole data in Hanging Woman Creek Study Area.

Classification

Coals can be classified in many ways (Tomkeieff, 1954, p. 9; Moore, 1940, p. 113; Francis, 1961, p. 361), but the classification by rank--that is, by degree of metamorphism in the progressive series that begins with peat and ends with graphocite (Schopf, 1966)--is the most commonly used system. Classification by type of plant materials is commonly used as a descriptive adjunct to rank classification when sufficient megascopic and microscopic information is available, and classification by type and quantity of impurities (grade) is frequently used when utilization of the coal is being considered.

Rank of Coal

The designation of a coal within the metamorphic series, which begins with peat and ends with graphocite, is dependent upon the temperature and pressure to which the coal has been subjected and the duration of time of subjection. Because coal is largely derived from plant material, it is mostly composed of carbon, hydrogen, and oxygen, along with smaller quantities of nitrogen, sulfur, and other elements. The increase in rank of coal as it undergoes progressive metamorphism is indicated by changes in the proportions of the major coal constituents: the higher rank coals have more carbon and less hydrogen and oxygen than the lower ranks.

Two standardized forms of coal analyses--the <u>proximate analysis</u> and the <u>ultimate analysis</u>--are generally made, though sometimes only the less complicated and less expensive <u>proximate analysis</u> is made. The analyses are described as follows (U.S. Bureau of Mines, 1965, p. 121-122).

> "The <u>proximate analysis</u> of coal involves the determination of four constituents: (1) water, called moisture; (2) mineral impurity, called ash, left when the coal is completely burned; (3) volatile matter, consisting of gases or vapors driven out when coal is heated to certain temperatures; and (4) fixed carbon, the solid or cakelike residue that burns at higher temperatures after volatile matter has been driven off. <u>Ultimate analysis</u> involves the determination of carbon and hydrogen as found in the gaseous products of combustion, the determination of sulfur, nitrogen, and ash in the material as a whole, and the estimation of oxygen by difference."

Most coals are burned to produce heat energy, so the heating value of the coal is an important property. The heating value (calorific value) is commonly expressed in British thermal units (Btu) per pound: 1 Btu is the amount of heat required to raise the temperature of 1 pound of water 1° F (1 Btu equals 0.252 kilocalories). Additional tests are sometimes made, particularly to determine caking, coking, and other properties, such as tar yield, that affect classification or utilization.

Figure 19 compares in histogram form the heating value, and the moisture, volatile matter, and fixed carbon contents of coals of different ranks.

Various schemes for classifying coals by rank have been proposed and used, but the one most commonly employed in the United States is the "Standard specifications for classification of coals by rank," adopted by the ASTM (American Society for Testing and Materials, 1977; Table 1). It is reproduced here as Table 3.

The ASTM classification system differentiates coals into classes and groups on the basis of mineral-matter-free fixed carbon or volatile matter, and the heating value supplemented by determination of agglomerating (caking) characteristics. "Coals which in the volatile matter determination produce either an agglomerate button that will support a 500-g weight without pulverizing, or a button showing swelling or cell structure, shall be considered agglomerating from the standpoint of classification" (ASTM, 1977, p. 216).

As pointed out by the ASTM (1977, p. 216), a standard rank determination cannot be made unless the samples were obtained in accordance with standardized sampling procedures (Snyder, 1950; Schopf, 1960). However, nonstandard samples may be used for comparative purposes through determinations designated as "apparent rank".

The apparent rank of the coals at the Hanging Woman Creek study area is sub-bituminous C.

Type of Coal

Classification of coals by type--that is, according to the types of plant materials present--takes many forms, such as the "rational analysis" of Francis (1961) or the semicommercial "type" classification commonly used in the coal fields of the eastern United States (U.S. Bureau of Mines, 1965, p. 123). However, most of the type classifications are based on the same or similar gross distinctions in plant material used by Tomkeieff (1954), Table II and p. 9), who divided the coals into three series; humic coals, humic-sapropelic coals, and sapropelic coals, based upon the nature of the original plant materials. The humic coals are largely composed of the remains of the woody parts of plants, and the sapropelic coals are largely composed of the more resistant waxy, fatty and resinous parts of plants, such as cell walls, spore-coatings, pollen, and resin particles, and coals composed mainly of algal material. Most coals fall into the humic series, with some coals being mixtures of humic and sapropelic elements and, therefore, falling into the humic-sapropelic series. The sapropelic series is quantitatively insignificant and when found is commonly regarded as an organic curiosity.

In common with most coals of the United States, the Hanging Woman Creek coals fall largely in the humic series.

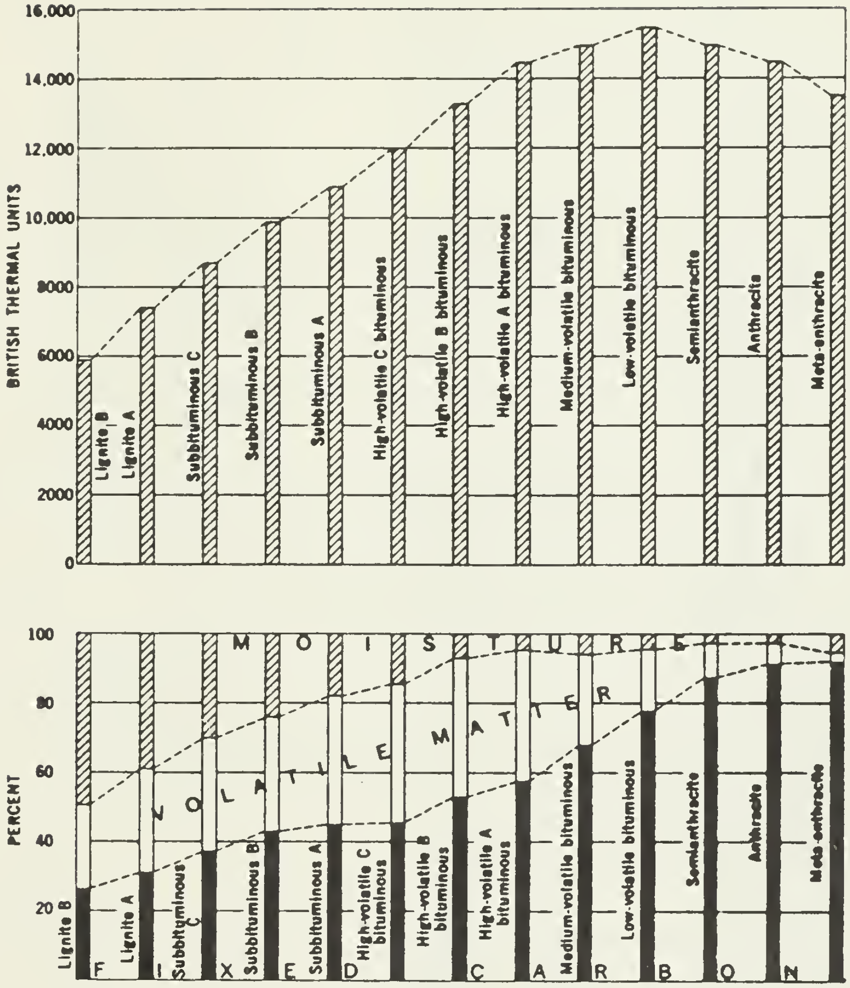


Figure 19. Comparison on Moist, Mineral-Matter-Free Basis of Heat Values; and Proximate Analyses of Coal of Different Ranks.

Table 3. Classification of coals by rank[1]

[American Society for Testing and Materials Standard D388-77 (Reapproved 1972);

1 Btu equals 0.252 kilogram-calories]

Class	Group	Fixed Carbon Limits, percent (Dry, Mineral-Matter-Free Basis)		Volatile Matter Limits, percent (Dry, Mineral Matter-Free Basis)		Calorific Value Limits, Btu per pound (Moist,[2] Mineral-Matter-Free Basis)		Agglomerating Character
		Equal or Greater Than	Less Than	Greater Than	Equal or Less Than	Equal or Greater Than	Less Than	
I. Anthracite	1. Meta-anthracite	98	---	---	2	---	---	nonagglomerating
	2. Anthracite	92	98	2	8	---	---	nonagglomerating
	3. Semianthracite[3]	86	92	8	14	---	---	nonagglomerating
II. Bituminous	1. Low volatile bituminous coal	78	86	14	22	---	---	commonly agglomerating[5]
	2. Medium volatile bituminous coal	69	78	22	31	---	---	commonly agglomerating[5]
	3. High volatile A bituminous coal	---	69	31	---	14 000[4]	---	commonly agglomerating[5]
	4. High volatile B bituminous coal	---	---	---	---	13 000[4]	14 000	commonly agglomerating[5]
	5. High volatile C bituminous coal	---	---	---	---	11 500	13 000	commonly agglomerating[5]
						10 500	11 500	agglomerating
III. Subbituminous	1. Subbituminous A coal	---	---	---	---	10 500	11 500	nonagglomerating
	2. Subbituminous B coal	---	---	---	---	9 500	10 500	nonagglomerating
	3. Subbituminous C coal	---	---	---	---	8 300	9 500	nonagglomerating
IV. Lignitic	1. Lignite A	---	---	---	---	6 300	8 300	nonagglomerating
	2. Lignite B					---	6 300	nonagglomerating

[1]This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 percent dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free British thermal units per pound.

[2]Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[3]If agglomerating, classify in low-volatile group of the bituminous class.

[4]Coals having 69 percent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

[5]It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and there are notable exceptions in high volatile C bituminous group.

Grade of Coal

Classification of coal by grade is based largely on the content of ash, sulfur, and other constituents that adversely affect utilization. Most detailed coal resource evaluations of the past do not categorize known coal resources by grade, but coals of the United States have been classified by sulfur content in a gross way (DeCarlo and others, 1966).

The range and average of the ash and sulfur contents of 642 coal samples from all parts of the United States were determined by Fieldner, Rice, and Moran (1942). Ash and sulfur contents of these U.S. coals as received were as follows:

Number of	Ash, percent		Sulfur, percent	
Samples	Range	Average	Range	Average
642	2.5 - 32.6	8.9	0.2 - 7.7	1.9

The Anderson and Dietz coal beds in the Hanging Woman Creek study area are well below average in ash and sulfur content.

Chemical Analyses of Coal in the Hanging Woman Creek Study Area

Thirteen coal samples from five coal beds were collected by the U.S. Geological Survey from the five core holes in the Hanging Woman Creek study area. These samples are briefly described in Table 4. Nine of the samples are from the Anderson bed (the principal coal bed of interest in this area), one from the Dietz coal bed 50 to 100 feet (15 to 30 m) below the Anderson bed, and one each from three thin coal beds 130 to 210 feet (40 to 64 m) above the Anderson bed (see Figure 18). Two samples were collected from the Anderson bed in each core hole, except in hole HWC-23 (locality H) where part of the core was lost. In hole HWC-20 (locality K, Figure 18), where the Anderson bed contains a shale parting near the base, one sample (D186445) was collected from the main bed above the parting; a second sample (D186446) represents the coal below the parting. In the other three holes the topmost 2.4 to 2.6 feet (0.73 to 0.79 m) were sampled separately from the main bed.

Proximate and ultimate analysis, heat content, air-dried loss, forms-of-sulfur, and ash-fusion temperature determinations on these samples were provided by the Coal Analysis Section, U.S. Bureau of Mines, Pittsburgh, Pennsylvania (Table 5). Analyses for 33 major and minor oxides and trace elements in the laboratory ash (Table 6) and analyses of nine trace elements in whole coal (Table 7) were provided by the U.S. Geological Survey in Denver, Colorado. Analytical procedures used by the U.S. Geological Survey are described in Swanson and Huffman (1976). Table 8 contains the data listed in Table 6 converted to a whole-coal basis and the whole-coal analyses listed in Table 7. Twenty-three additional elements were looked for but not found in amounts greater than their lower limits of detection (Table 9). Unweighted statistical summaries of the analytical data in Tables 5, 6, and 8 are listed in Tables 10, 11 and 12, respectively. Data summaries for other Powder River regional coal samples are listed for comparison.

Table 4. -- USGS sample number, hole number, locality number, depth interval, and bed name for 13 coal samples from cores of drill holes in the Hanging Woman Creek study area, Big Horn County, Montana.

[All samples are from the Fort Union Formation of Paleocene age. See Figure 18 for locations and data on drill holes]

USGS Sample Number	Hole Number	Map Locality number	Depth interval feet and (meters)	Coal Bed Name
D186451	HWC-27	C	23.0-27.2 (7.0-8.3)	Waddle
D186452	HWC-27	C	69.0-70.6 (21.0-21.5)	Unnamed
D186453	HWC-27	C	101.5-105.0 (30.9-32.0)	Smith
D186454	HWC-27	C	230.5-233.0 (70.2-71.0)	Anderson
D186455	HWC-27	C	233.0-259.2 (71.0-79.0)	Anderson
D186456	HWC-23	H	138.0-166.7 (42.1-50.8)	Anderson
D186443	HWC-21	A	114.0-116.5 (34.8-35.5)	Anderson
D186444	HWC-21	A	116.5-141.0 (35.5-43.0)	Anderson
D186445	HWC-20	K	93.4-119.5 (28.5-36.4)	Anderson
D186446	HWC-20	K	120.5-122.0 (36.7-37.2)	Anderson
D186448	HWC-25	L	73.0-75.5 (22.3-23.0)	Anderson
D186449	HWC-25	L	75.5-106.0 (23.0-32.3)	Anderson
D186450	HWC-25	L	165.5-176.6 (50.4-53.8)	Dietz

Table 5.--Proximate and ultimate analyses, heat content, forms-of-sulfur, free-swelling-index and ash fusion temperature determinations for 13 coal samples from Hanging Woman Creek study area, Big Horn County, Montana.

[All analyses except heat content, free-swelling-index and ash fusion temperatures in percent. For each sample number, the analyses are reported three ways; first, as received, second, moisture free, and third, moisture and ash free. All analyses by Coal Analysis Section, U.S. Bureau of Mines, Pittsburgh, Pa. °C = (°F-32) 5/9. Leaders (---) indicate no data.]

Sample number	Proximate Analysis				Ultimate Analysis					Heat Content	
	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Kcal/kg	Btu/lb.
D186451	27.7	30.9	34.2	7.2	6.5	47.9	1.1	35.6	1.7	4,650	8,370
	---	42.7	47.3	10.0	4.7	66.3	1.5	15.2	2.4	6,430	11,570
	---	47.5	52.5	---	5.3	73.6	1.7	16.9	2.6	7,140	12,860
D186452	29.5	29.3	34.8	6.4	6.4	47.4	1.2	38.0	.6	4,570	8,230
	---	41.6	49.4	9.1	4.4	67.2	1.7	16.7	.9	6,490	11,680
	---	45.7	54.3	---	4.9	73.9	1.9	18.4	.9	7,130	12,840
D186453	27.0	28.1	36.3	8.6	6.2	47.5	1.2	35.6	.9	4,560	8,210
	---	38.5	49.7	11.8	4.4	65.1	1.6	15.9	1.2	6,250	11,250
	---	43.6	56.4	---	5.0	73.8	1.9	18.0	1.4	7,090	12,750
D186454	27.9	27.6	40.5	4.0	6.4	50.9	1.0	37.5	.3	4,820	8,670
	---	38.3	56.2	5.5	4.6	70.6	1.4	17.6	.4	6,680	12,030
	---	40.5	59.5	---	4.8	74.7	1.5	18.6	.4	7,070	12,730
D186455	28.8	28.7	38.8	3.7	6.6	50.2	1.1	38.2	.2	4,810	8,660
	---	40.3	54.5	5.2	4.8	70.5	1.5	17.7	.3	6,760	12,170
	---	42.5	57.5	---	5.0	74.4	1.6	18.7	.3	7,130	12,840
D186456	27.4	29.8	37.3	5.5	6.4	49.8	1.0	36.6	.5	4,790	8,620
	---	41.0	51.4	7.6	4.6	68.6	1.4	16.9	.7	6,600	11,870
	---	44.4	55.6	---	5.0	74.2	1.5	18.2	.7	7,140	12,850
D186443	26.7	28.4	38.8	6.1	6.3	50.5	1.1	35.7	.3	4,780	8,610
	---	38.7	52.9	8.3	4.5	68.9	1.5	16.3	.4	6,530	11,740
	---	42.3	57.7	---	5.0	75.1	1.6	17.8	.4	7,120	12,810
D186444	27.9	28.6	38.2	5.3	6.3	50.0	1.0	36.9	.4	4,740	8,540
	---	39.7	53.0	7.4	4.4	69.3	1.4	16.8	.6	6,580	11,840
	---	42.8	57.2	---	4.8	74.9	1.5	18.1	.6	7,100	12,790
D186445	27.5	29.7	38.3	4.5	6.5	50.8	1.0	36.9	.3	4,840	8,720
	---	41.0	52.8	6.2	4.8	70.1	1.4	17.2	.4	6,680	12,040
	---	43.7	56.3	---	5.1	74.7	1.5	18.3	.4	7,120	12,820
D186446	23.3	26.9	26.3	23.5	5.5	36.3	.7	29.4	4.5	3,600	6,480
	---	35.1	34.3	30.6	3.8	47.3	.9	11.3	5.9	4,690	8,440
	---	50.6	49.4	---	5.5	68.2	1.3	16.3	8.5	6,760	12,180
D186448	29.8	28.0	37.0	5.2	6.4	48.8	.9	38.5	.3	4,600	8,290
	---	39.9	52.7	7.4	4.4	69.5	1.3	17.1	.4	6,560	11,810
	---	43.1	56.9	---	4.8	75.1	1.4	18.5	.5	7,080	12,750
D186449	29.9	29.3	35.7	5.1	6.7	48.3	1.0	38.3	.7	4,650	8,370
	---	41.8	50.9	7.3	4.8	68.9	1.4	16.7	1.0	6,630	11,940
	---	45.1	54.9	---	5.2	74.3	1.5	18.0	1.1	7,150	12,880
D186450	28.6	29.0	35.5	6.9	6.4	48.2	1.0	36.9	.6	4,610	8,300
	---	40.6	49.7	9.7	4.5	67.5	1.4	16.1	.8	6,460	11,620
	---	45.0	55.0	---	5.0	74.7	1.6	17.8	.9	7,150	12,870

Table 5.--Proximate and ultimate analyses, heat content, forms-of-sulfur, free-swelling-index and ash fusion temperature determinations for 13 coal samples from Hanging Woman Creek study area, Big Horn County, Montana.--Continued.

Sample number	Air-dried loss	Forms of Sulfur Sulfate	Pyritic	Organic	Free swelling	Ash fusion temperature C Initial deform.	soften	fluid
D186451	19.8	0.01	0.55	1.19	0.0	1,100	1,150	1,215
	---	.01	.76	1.65				
	---	.02	.84	1.83				
D186452	20.9	.01	.18	.44	.0	1,125	1,175	1,225
	---	.01	.18	.62				
	---	.02	.28	.69				
D186453	19.2	.02	.28	.59	.0	1,125	1,180	1,240
	---	.03	.38	.81				
	---	.03	.43	.92				
D186454	20.0	.01	.14	.13	.0	1,115	1,170	1,215
	---	.01	.19	.18				
	---	.01	.21	.19				
D186455	21.9	.01	.08	.13	.0	1,100	1,155	1,210
	---	.01	.11	.18				
	---	.01	.12	.19				
D186456	18.6	.01	.22	.28	.0	1,100	1,155	1,205
	---	.01	.30	.39				
	---	.01	.33	.42				
D186443	18.7	.01	.20	.07	.0	1,125	1,175	1,235
	---	.01	.27	.10				
	---	.01	.30	.10				
D186444	18.4	.02	.20	.19	.0	1,085	1,145	1,195
	---	.03	.28	.26				
	---	.03	.30	.28				
D186445	19.0	.01	.13	.20	.0	1,125	1,175	1,230
	---	.01	.18	.28				
	---	.01	.19	.29				
D-186446	17.3	.02	3.12	1.40	.0	1,070	1,125	1,180
	---	.03	4.07	1.83				
	---	.04	5.86	2.63				
D186448	20.9	.01	.14	.12	.0	1,150	1,205	1,270
	---	.01	.20	.17				
	---	.02	.22	.18				
D186449	21.3	.01	.25	.44	.0	1,170	1,225	1,290
	---	.01	.36	.63				
	---	.02	.38	.68				
D186450	20.6	.01	.20	.37	.0	1,100	1,155	1,205
	---	.01	.28	.52				
	---	.02	.31	.57				

Table 6.--Major and minor oxide and trace element composition of the laboratory ash of 13 coal samples from Hanging Woman Creek study area, Big Horn County, Montana.

[Values in percent or parts-per-million. Coal ashed at 525°C. L means less than the value shown; N, not detected: B, not determined; S after element title indicates determinations by semiquantative emissionspectrography; to be identified with geometric brackets whose boundaries are part of the ascending series 0.12, 0.18, 0.26, 0.38, 0.56, 0.83, 1.2, etc., but reported as mid-points of the brackets, 0.1, 0.15, 0.2, 0.3, 0.5, 0.7, 1.0, etc. Precision of the spectrographic data is plus-or-minus one bracket at 68 percent or plus-or-minus two brackets at 95 percent confidence level.]

Sample number	Ash (percent)	SiO2 (percent)	Al2O3 (percent)	CaO (percent)	MgO (percent)	Na2O (percent)	K2O (percent)	Fe2O3 (percent)	TiO2 (percent)	P2O5 (percent)	Sample number
D186451	9.2	21	11	13	5.60	0.73	0.57	21	0.74	1.0L	D186451
D186452	7.7	31	13	18	4.10	5.38	.82	6.8	.89	1.0L	D186452
D186453	9.5	31	9.1	14	4.28	4.40	1.5	14	.60	1.0L	D186453
D186454	5.6	29	12	23	4.75	6.58	.44	4.7	1.3	2.8	D186454
D186455	4.5	27	12	23	4.93	7.50	.32	7.1	2.0	1.0L	D186455
D186456	6.2	24	15	21	4.18	6.33	.37	7.7	1.4	1.0L	D186456
D186443	6.7	39	9.2	19	3.83	6.18	.24	5.9	1.5	1.0L	D186443
D186444	6.3	27	13	18	3.80	6.80	.57	7.2	1.1	1.0L	D186444
D186445	5.2	22	11	26	5.25	7.25	.22	6.3	1.6	1.0L	D186445
D186446	25.1	37	14	5.0	1.68	1.83	1.6	27	.70	1.0L	D186446
D186448	6.2	35	8.3	23	7.60	2.85	.20	3.4	1.5	1.3	D186448
D186449	5.8	17	10	24	7.58	3.00	.25	11	1.1	1.0L	D186449
D186450	7.2	33	11	18	3.93	5.38	.50	6.8	1.3	1.0L	D186450

Sample number	SO3 (percent)	Ag-S (ppm)	B-S (ppm)	Ba-S (ppm)	Be-S (ppm)	Cd (ppm)	Ce-S (ppm)	Cu (ppm)	Ga-S (ppm)	Ge-S (ppm)	Sample number
D186451	25	N	500	3,000	7	1.5	500L	145	20	N	D186451
D186452	20	N	700	1,500	15	1.0	500L	174	70	70	D186452
D186453	22	N	700	2,000	7	1.0L	N	99	30	30	D186453
D186454	13	N	700	10,000	7	1.0L	500L	89	20	N	D186454
D186455	11	N	700	10,000	3L	1.0L	N	191	15	N	D186455
D186456	20	N	500	7,000	3	2.0	N	227	20	N	D186456
D186443	15	N	700	7,000	3	1.5	N	181	15	N	D186443
D186444	21	N	700	5,000	N	1.0	N	201	20	N	D186444
D186445	16	N	700	7,000	3L	1.0	N	170	15	N	D186445
D186446	8.9	N	150	700	7	1.0	N	168	30	N	D186446
D186448	12	N	700	5,000	N	1.0L	N	109	15	N	D186448
D186449	24	N	700	3,000	3L	1.0	N	178	20	N	D186449
D186450	19	2	700	7,000	7	1.0L	N	125	30	N	D186450

Table 6.--Major and minor oxide and trace element composition of the laboratory ash of 13 coal samples from Hanging Woman Creek study area, Big Horn County, Montana.--Continued

Sample number	La-S (ppm)	Li (ppm)	Mn (ppm)	Mo-S (ppm)	Nb-S (ppm)	Ni-S (ppm)	Pb (ppm)	Sc-S (ppm)	Sr-S (ppm)	V-S (ppm)	Sample number
D186451	100L	28	124	15	20	70	35	20	2 000	300	D186451
D186452	N	28	154	15	30	150	75	30	2 000	300	D186452
D186453	N	22	466	20	30	70	30	30	1,500	200	D186453
D186454	100L	19	160	10	20	30	25L	20	7.000	100	D186454
D186455	N	28	290	7	20L	30	45	20	5 000	150	D186455
D186456	100L	58	150	15	20L	30	45	20	3.000	200	D186456
D186443	100L	36	158	7	30	20	80	20	3,000	100	D186443
D186444	100L	40	196	15	20L	30	80	15	3,000	150	D186444
D186445	100L	25	224	15	20	20	50	20	5 000	150	D186445
D186446	N	46	132	15	20L	70	25	30	500	150	D186446
D186448	N	15	230	7	20L	15	25	10	3,000	70	D186448
D186449	100L	34	212	10	20L	30	40	15	2,000	150	D186449
D186450	N	32	188	10	30	30	30	15	2 000	150	D186450

Sample number	Y-S (ppm)	Yb-S (ppm)	Zn (ppm)	Zr-S (ppm)
D186451	100	10	163	100
D186452	70	7	140	300
D186453	70	7	231	200
D186454	70	7	168	150
D186455	50	7	59	150
D186456	70	7	131	150
D186443	70	7	70	200
D186444	30	3	101	150
D186445	50	5	79	150
D186446	30	B	137	150
D186448	50	3	118	150
D186449	50	5	90	100
D186450	70	7	79	150

Table 7.--Content of nine trace elements in 13 coal samples from Hanging Woman Creek study area, Big Horn County, Montana.

[Analyses on air-dried (32°C) coal. Values in parts-per-million (ppm). L, less than the value shown, B, not determined.]

Sample number	As (ppm)	Co (ppm)	Cr (ppm)	F (ppm)	Hg (ppm)	Sb (ppm)	Se (ppm)	Th (ppm)	U (ppm)	Sample number
D186451	16	B	5.6	65	0.12	0.3	0.1L	2.2	2.7	D186451
D186452	2.4	2.4	5.1	45	.03	.7	.5	1.0	.6	D186452
D186453	15	5.1	6.7	50	.07	3.1	.9	.8	1.5	D186453
D186454	.6	.8	2.5	35	.01	.2	.3	.7	.2L	D186454
D186455	.5	.9	2.4	30	.02	.1	.2	.6	.2L	D186455
D186456	1.1	1.1	3.2	40	.06	.2	.8	.9	.8	D186456
D186443	1.1	.5	2.5	30	.05	.1	.7	.6	.6	D186443
D186444	.8	1.1	3.2	40	.04	.1	.5	.9	.5	D186444
D186445	.8	.8	1.9	30	.03	.1	.6	.8	.6	D186445
D186446	39	5.2	27	115	.18	.8	.1L	3.3	4.6	D186446
D186448	.4	.5	2.3	35	.05	.1	.3	1.0	.5	D186448
D186449	2.5	1.5	2.6	40	.08	.1	.7	.7	.7	D186449
D186450	2.7	2.0	3.7	50	.07	.4	.7	1.0	.7	D186450

Table 8.--Major, minor, and trace element composition of 13 coal samples from Hanging Woman Creek study area, Big Horn County, Montana.

[Values in percent or parts-per-million. As, F, Hg, Sb, Se, Th, U, values are from direct determinations on air dried (32°C) coal; all other values calculated from analyses of ash. S means analysis by emissionspectrography; L, less than the value shown; N, not detected; B, not determined.]

Sample number	Si (percent)	Al (percent)	Ca (percent)	Mg (percent)	Na (percent)	K (percent)	Fe (percent)	Ti (percent)	Ag-S (ppm)	As (ppm)	Sample number
D186451	0.90	0.54	0.85	0.31	0.050	0.044	1.4	0.041	N	16	D186451
D186452	1.1	.53	.99	.19	.31	.053	.37	.041	N	2.4	D186452
D186453	1.4	.46	.95	.24	.31	.12	.93	.034	N	15	D186453
D186454	.76	.36	.92	.16	.27	.021	.18	.044	N	.6	D186454
D186455	.57	.29	.74	.13	.25	.012	.22	.054	N	.5	D186455
D186456	.69	.49	.93	.16	.29	.019	.33	.052	N	1.1	D186456
D186443	1.2	.33	.91	.15	.31	.013	.28	.060	N	1.1	D186443
D186444	.79	.43	.81	.14	.32	.030	.32	.042	N	.8	D186444
D186445	.53	.30	.97	.16	.28	.010	.23	.050	N	.8	D186445
D186446	4.3	1.9	.90	.25	.34	.33	4.7	.11	N	39	D186446
D186448	1.0	.27	1.0	.28	.13	.010	.15	.056	N	.4	D186448
D186449	.46	.31	.99	.26	.13	.012	.45	.038	N	2.5	D186449
D186450	1.1	.42	.93	.17	.29	.030	.34	.056	.15	2.7	D186450

Sample number	B-S (ppm)	Ba-S (ppm)	Be-S (ppm)	Cd (ppm)	Ce-S (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	F (ppm)	Ga-S (ppm)	Sample number
D186451	50	300	0.7	0.14	50L	B	5.6	13	65	2	D186451
D186452	50	100	1	.08	50L	2.4	5.1	13	45	5	D186452
D186453	70	200	.7	.09L	N	5.1	6.7	9.4	50	3	D186453
D186454	50	500	.5	.06L	30L	.8	2.5	5.0	35	1	D186454
D186455	30	500	.15L	.04L	N	.9	2.4	8.6	30	.7	D186455
D186456	30	500	.2	.12	N	1.1	3.2	14	40	1.5	D186456
D186443	50	500	.2	.10	N	.5	2.5	12	30	1	D186443
D186444	50	300	N	.06	N	1.1	3.2	13	40	1.5	D186444
D186445	30	300	.15L	.05	N	.8	1.9	8.8	30	.7	D186445
D186446	30	150	1.5	.25	N	5.2	27	42	115	7	D186446
D186448	50	300	N	.06L	N	.5	2.3	6.8	35	1	D186448
D186449	50	150	.15L	.06	N	1.5	2.6	10	40	1	D186449
D186450	50	500	.5	.07L	N	2.0	3.7	9.0	50	2	D186450

Table 8.--Major, minor, and trace element composition of 13 coal samples from Hanging Woman Creek study area, Big Horn County, Montana.
--Continued

Sample number	Ge-S (ppm)	Hg (ppm)	La-S (ppm)	Li (ppm)	Mn (ppm)	Mo-S (ppm)	Nb-S (ppm)	Ni-S (ppm)	P (ppm)	Pb (ppm)	Sample number
D186451	N	0.12	10L	2.6	11	1.5	2	7	400L	3.2	D186451
D186452	5	.03	N	2.2	12	1	2	10	340L	5.8	D186452
D186453	3	.07	N	2.1	44	2	3	7	420L	2.8	D186453
D186454	N	.01	5L	1.1	9.0	.5	1	1.5	690	1.4L	D186454
D186455	N	.02	N	1.3	13	.3	1L	1.5	200L	2.0	D186455
D186456	N	.06	7L	3.6	9.3	1	1.5L	2	270L	2.8	D186456
D186443	N	.05	7L	2.4	11	.5	2	1.5	290L	5.4	D186443
D186444	N	.04	7L	2.5	12	1	1.5L	2	280L	5.0	D186444
D186445	N	.03	5L	1.3	12	.7	1	1	230L	2.6	D186445
D186446	N	.18	N	12	33	3	5L	15	1,100L	6.3	D186446
D186448	N	.05	N	.9	14	.5	1.5L	1	350	1.5	D186448
D186449	N	.08	7L	2.0	12	.7	1L	1.5	250L	2.3	D186449
D186450	N	.07	N	2.3	14	.7	2	2	310L	2.2	D186450

Sample number	Sb (ppm)	Sc-S (ppm)	Se (ppm)	Sr-S (ppm)	Th (ppm)	U (ppm)	V-S (ppm)	Y-S (ppm)	Yb-S (ppm)	Zn (ppm)	Zr-S (ppm)
D186451	0.3	2	0.1L	200	2.2	2.7	30	10	1	15	10
D186452	.7	2	.5	150	1.0	.6	20	5	.5	11	20
D186453	3.1	3	.9	150	.8	1.5	20	7	.7	22	20
D186454	.2	1	.3	500	.7	.2L	5	5	.5	9.4	10
D186455	.1	1	.2	200	.6	.2L	7	2	.3	2.7	7
D186456	.2	1.5	.8	200	.9	.8	15	5	.5	8.1	10
D186443	.1	1.5	.7	200	.6	.6	7	5	.5	4.7	15
D186444	.1	1	.5	200	.9	.5	10	2	.2	6.4	10
D186445	.1	1	.6	200	.8	.6	7	2	.2	4.1	7
D186446	.8	7	.1L	150	3.3	4.6	30	7	B	34	30
D186448	.1	.7	.3	200	1.0	.5	5	3	.2	7.3	10
D186449	.1	1	.7	100	.7	.7	10	3	.3	5.2	7
D186450	.4	1	.7	150	1.0	.7	10	5	.5	5.7	10

Table 9. Elements looked for, but not detected in Hanging Woman Creek study area coal samples.

[Approximate lower detection limits for these elements in coal ash, by the six-step spectrographic method of the U.S. Geological Survey, are included.]

Element	Lower limit of detection (ppm) in coal ash
Au	50
Bi	20
Dy	100
Er	100
Eu	200
Gd	100
Hf	200
Ho	50
In	20
Lu	70
Nd	150
Pd	5
Pr	200
Pt	100
Re	100
Sm	200
Sn	20
Ta	1,000
Tb	700
Te	5,000
Tl	100
Tm	50
W	200

Table 10.--Arithmetic mean, observed range, geometric mean, and geometric deviation of proximate and ultimate analyses, heat content, forms-of-sulfur and ash fusion temperatures for 13 coal samples from the Hanging Woman Creek study area, Big Horn County, Montana. For comparison, geometric means from 33 Powder River region, Wyoming coal samples (Swanson and others, 1976, Tables 31b and 32b) are included.

[All values are in percent except Kcal/kg, Btu/lb and ash fusion temperatures and are reported on the as-received basis. °C = (°F-32) 5/9. Leaders (--) indicate no data.]

	Arithmetic mean	Observed range minumum	Observed range maximum	Geometric mean	Geometric deviation	Powder River Region, Wyo. geometric mean
			Proximate and ultimate analyses			
Moisture	27.9	23.3	29.9	27.8	1.1	23.1
Volatile matter	28.8	26.9	30.9	28.8	1.0	32.0
Fixed carbon	36.3	26.3	40.5	36.1	1.1	36.0
Ash	6.9	3.7	23.5	6.2	1.6	7.5
Hydrogen	6.4	5.5	6.7	6.3	1.1	6.2
Carbon	48.2	36.3	50.9	48.0	1.1	50.3
Nitrogen	1.0	.7	1.2	1.0	1.2	.9
Oxygen	36.5	29.4	38.5	36.4	1.1	32.9
Sulfur	.8	.2	4.5	.6	2.3	.8
			Heat content			
Kcal/kg	4,620	3,600	4,850	4,610	1.1	4,860
Btu/lb	8,310	6,480	8,720	8,290	---	8,740
			Forms-of-sulfur			
Sulfate	0.01	0.01	0.02	0.01	1.4	0.02
Pyrite	.35	.08	3.1	.24	2.5	.29
Organic	.43	.07	1.4	.29	2.5	.31
			Ash fusion temperature °C			
Initial leformation	1,114	1,068	1,168	1,114	1.0	----
Softening emperature	1,169	1,124	1,227	1,169	1.0	----
Fluid ature	1,224	1,179	1,291	1,223	1.0	----

Table 11.--Arithmetic mean, observed range, geometric mean, and geometric deviation of ash content and contents of nine major and minor oxides in the laboratory ash of 13 coal samples from the Hanging Woman Creek study area, Big Horn County, Montana. For comparison, geometric means for 410 Powder River region coal samples are listed (Hatch and Swanson, 1977, Table 6a).

[All samples were ashed at 525°C; all analyses are in percent.]

Oxide	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Powder River region geometric mean
		minimum	maximum			
(Ash)	7.9	4.5	25.1	7.2	1.5	9.0
SiO_2	29	17	39	28	1.3	28
Al_2O_3	11	8.3	15	11	1.2	14
CaO	19	5	26	18	1.5	15
MgO	4.8	1.7	7.6	4.4	1.5	3.6
Na_2O	5.3	.73	7.5	4.2	2.0	.93
K_2O	.58	.20	1.6	.46	2.0	.28
Fe_2O_3	9.9	3.4	27	8.3	1.8	5.8
TiO_2	1.2	.6	2.0	1.1	1.4	.61
SO_3	18	8.9	25	17	1.4	14

Table 12.--Arithmetic mean, observed range, geometric mean and geometric deviation of 28 elements in 13 coal samples from the Hanging Woman Creek study area, Big Horn County, Montana. For comparison, geometric means for 410 Powder River region coal samples are listed (Hatch and Swanson, 1977, Table 6b)

[All analyses are in parts per million and are reported on a whole-coal basis. As, Co, Cr, F, Hg, Sb, Se, Th and U values used to calculate the statistics were determined directly on whole coal. All other values used were calculated from determinations made on coal ash. L, less than the value shown]

Element	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Powder River region geometric mean
		minimum	maximum			
As	5.6	0.4	39	2.1	4.3	2
B	50	30	70	50	1.3	50
Ba	300	100	500	300	1.7	300
Be	.7	.15L	1.5	.5	2.0	.5
Cd	.1	.04L	.25	.09	1.7	.04
Co	1.8	.5L	5.2	1.3	2.2	2
Cr	4.8	1.9	27	3.8	2.0	5
Cu	13	5.0	42	11	1.7	9.5
F	46	30	115	43	1.5	40
Ga	2	.7	7	1.5	2.1	2
Hg	.06	.01	.8	.05	2.1	.08
Li	2.6	1.1	12	2.2	1.9	3.9
Mn	16	9.0	44	14	1.6	34
Mo	1	.3	3	1	1.9	1.5
Nb	2	1L	3	1.5	1.5	1
Ni	5	1	15	3	2.5	3
Pb	3.5	1.4L	6.3	3.2	1.6	5.1
Sb	.4	.1	3.1	.2	3.0	.4
Sc	2	.7	7	1.5	1.9	1.5
Se	.6	.1L	.9	.5	1.6	.7
Sr	200	100	500	200	1.4	150
Th	1.1	.6	3.3	1.0	1.6	3.3
U	1.2	.2L	4.6	.9	2.1	.6
V	15	5	30	10	1.9	10
Y	5	2	10	5	1.7	3
Yb	.5	.2	1	.5	1.7	.3
Zn	10	2.7	34	8.1	2.0	13
Zr	15	7	30	10	1.6	15

Eight analyses (as received basis) of the Anderson coal (Table 5), excluding the analysis of the coal below the parting in hole HWC-20 (D186446), show that its ash contents range from 3.7 to 6.1 percent, averaging 4.9 percent; its sulfur contents range from 0.2 to 0.7 percent, averaging 0.4 percent; and its heat content ranges from 4,600 to 4,800 Kcal/kg (8,290 to 8,720 Btu/lb) averaging 4,750 Kcal/kg (8,540 Btu/lb). The coal below the parting in HWC-20 (locality L) has a high ash and sulfur content (D186446), and presumably would not be mined with the coal above the parting. The one analysis of the Dietz bed (D186450) shows that its ash content is 6.4 percent, its sulfur content is 0.6 percent and its heating value is 4,610 Kcal/kg (8,300 Btu/lb).

The analyses of all 13 coal samples show that the apparent rank of all coal sampled is sub-bituminous C, as calculated according to ASTM designation D-388-77 (ASTM, 1977). In Table 10, the geometric mean of the 13 chemical analyses are compared with the geometric mean of analyses of 33 coal samples from other areas in the Powder River region, as listed in Swanson and others (1976). Note that the arithmetic mean of the 13 coal samples can be misleading because analyses of thin beds with high ash and sulfur contents are averaged with thick beds with low ash and sulfur contents. A comparison of the geometric means shows no significant statistical difference (student's $\underline{t}$ test, 95% confidence level) between the coal samples in the Hanging Woman Creek study area, and the 33 samples from the Powder River region.

In Table 11, the geometric mean of the contents of nine major and minor oxides in the laboratory ash of 13 coal samples are compared with the geometric mean of these oxides in 410 Powder River region samples. The values are similar (student's $\underline{t}$ test, 95% confidence level) except for the contents of Na_2O and TiO_2 which are significantly higher and Al_2O_3 which is significantly lower in the Hanging Woman Creek samples. At the 99% confidence level, only Na_2O and TiO_2 contents are significantly different.

In Table 12, the geometric mean of the content of 28 elements in the 13 coal samples are compared with the geometric mean of these elements in 410 Powder River basin samples. The contents for most elements are similar (student's $\underline{t}$ test, 95% confidence level) except for the contents of Cd, Y, and Yb which are significantly higher and the contents of Co, Hg, Li, Mn, Pb, Th, and Zn which are significantly lower in the Hanging Woman Creek samples. At the 99% confidence level, only Cd, Mn, Th, and Zn are significantly different.

As indicated by the statistics, coal from the Hanging Woman Creek study area is similar in chemical composition to other coals in the Powder River region. Powder River region coals are characterized by low ash, low sulfur, relatively low heat and high moisture contents. The contents of elements of environmental concern (As, Be, Cd, Hg, Mo, Sb, Se, etc.) in Powder River region coal are generally low when compared to contents in Interior province coal (Hatch and Swanson, 1977). Powder River region coals are or will be used in coal-fired power generating or coal gasification plants.

Explanation of Statistical Terms used in Summary Tables

In this report the geometric mean (GM) is used as the estimate of the most probable concentration (mode); the geometric mean is calculated by taking the logarithm of each analytical value, summing the logarithms, dividing the sum by the total number of values and obtaining the antilogarithms of the result. The measure of scatter about the mode used here is the geometric deviation (GD) which is the antilog of the standard deviation of the logarithms of the analytical values. These statistics are used because of the common tendency for the amounts of trace elements in natural materials to exhibit positively skewed frequency distributions; these distributions are normalized by analyzing and summarizing trace element data on a logarithmic basis.

If the frequency distributions are lognormal, the geometric mean is the best estimate of the mode, and the estimated range of the central two-thirds of the observed distribution has a lower limit equal to GM/GD and an upper limit equal to GM·GD. The estimated range of the central 95% of the observed distribution has a lower limit equal to $GS/(GD)^2$ and an upper limit equal to $GM \cdot (GD)^2$ (Connor and others, 1976).

Although the geometric mean is, in general, an adequate estimate of the most common analytical value, it is, nevertheless, a biased estimate of the arithmetic mean. In the summary tables of data, the estimates of the arithmetic means are Sichel's $\underline{t}$ statistic (Miesch, 1967).

A common problem in statistical summaries of trace element data arises when the element content in one or more of the samples is below the limit of analytical detection. This results in a "censored" distribution. Procedures developed by Cohen (1959) were used to compute unbiased estimates of the geometric mean, geometric deviation, and arithmetic mean where the data are censored.

Estimation and Classification of Coal Resources

In preparing the coal resource estimates for the Hanging Woman Creek study area, the procedures and definitions used are those of the Coal Resources Classification System of the U.S. Bureau of Mines and the U.S. Geological Survey, which is published as U.S. Geological Survey Bulletin 1450-B. As used herein, the term "coal resources" designates the estimated quantity of coal in the ground in such form that economic extraction is currently or potentially feasible. Identified Resources are specific bodies of coal whose location, rank, quality, and quantity are known from geologic evidence supported by engineering measurements.

Tabulation of Coal Resources

Table 13 summarizes that part of the Identified coal resources in the study area that have potential for recovery by surface mining methods, which in this area is assumed to be coal within 200 feet (60 m) of the surface. As such, these coal resources fall into a category called

Reserve Base, which is defined as that part of Identified Coal Resource from which Reserves are calculated. Reserves are the actual amount of coal that can be economically recovered from this deposit at this time considering all legal, technological, and environmental restraints and are calculated by applying a percent Recovery Factor to Reserve Base. This Recovery Factor takes into account all coal remaining in the ground after mining is completed - considered to be "lost in mining" - and includes all coal (1) left unmined beneath rivers, lakes, highways, and legal reservations, (2) left unmined adjacent to mine or property boundaries, or (3) left unmined because of environmental, quality, safety, hydrologic or legal restrictions. In the United States, the Recovery Factor for surface mining methods locally exceeds 90%. No Recovery Factor was applied to the Reserve Base coal in this area because of the many uncertainties about legal and other restrictions on surface mining.

Table 13. Estimated resources of surface-minable coal in the Anderson and Dietz coal beds, Hanging Woman Creek study area, Big Horn County, Montana.

[In millions of short tons. 1 short ton = 0.907 metric tons. 1 foot = 0.305 m.]

Overburden thickness (in feet)	Measured	Indicated	Inferred	Total
Anderson coal bed				
0-100	40.34	97.31	0.64	138.29
100-200	27.11	136.96	75.76	239.83
Total	67.45	234.27	76.40	378.12
Dietz coal bed				
0-200[1/]	10.56	37.04	7.75	55.35
Grand Total	78.01	271.31	84.15	433.47

1/ Almost everywhere the overburden above the Dietz bed includes the Anderson coal bed, which is 50-100 feet above.

Characteristics Used in Resource Evaluation

The characteristics used in evaluating resources can be divided into two main classes: (1) those that affect the economic feasibility of recovery and utilization of coal, and (2) those that characterize the coal resources according to the degree of geologic assurance that the coal resources exist in the amount stated. Characteristics affecting the economic feasibility of recovery and utilization of the coal include such

factors as rank, grade, and density of the coal, and the depth and thickness of the bed. The rank and the grade of the coal in this area have been discussed previously.

Density

The density of the coal, or weight per unit volume, varies considerably with differences in rank and ash content. In areas such as the Hanging Woman Creek study area, where the density or specific gravity of the coals have not been determined, an average density or specific gravity based on determinations from other areas is used. For sub-bituminous coal, the average density is taken as 1,770 short tons per acre-foot, and the average specific gravity is 1.30.

Thickness of Coal Beds

Because the thickness of coal beds is an important factor in determining the economic feasibility of recovery, most coal resource estimates prepared by the U.S. Geological Survey are tabulated according to three thickness categories. For sub-bituminous coal the categories are (1) thin, 2.5 to 5 feet (.75 to 1.5 m), (2) intermediate - 5 to 10 feet (1.5 to 3m), and (3) thick - more than 10 feet (3 m). In the study area, all of resources tabulated in the Anderson coal bed are in the thick category, and the resources for the Dietz coal bed are both intermediate and thick (Figure 17).

The data on the thickness of the coal beds in the study area are from holes drilled by the Montana Bureau of Mines and Geology (see Figure 18), and from gamma ray logs of oil and gas test holes in and near the study area. The thicknesses of coal interpreted from these data are judged to be accurate within 1 foot (0.3 m).

Depth of Coal Bed

Coal resources are commonly divided into categories based on the depth of the coal bed, as follows: 0-1,000 feet (0-300 m), 1,000-2,000 feet (300-600 m), 2,000-3,000 feet (600-900 m) and 3,000-6,000 feet (900-1,800 m). Additional categories of depth for coal resources that can be recovered by surface mining methods are not standardized, because of the many factors that affect the amount of overburden that can be economically removed from a coal deposit. In this area it is assumed that coal beds to a depth of 200 feet (60 m) can be economically mined by surface-mining methods.

Resource Categories According to Degree of Geologic Assurance

The coal resources tabulated for the study area are all in the Identified category of geologic assurance, and are further subdivided into Measured, Indicated, and Inferred categories based on the nearness of the coal to a measurement of the coal bed, and on geologic evidence and projection.

Measured. - Coal for which estimates of the rank, quality, and quantity have been computed, within a margin of error of less than 20 percent, from sample analyses and measurements from closely spaced and geologically well-known sample sites. In this area, Measured coal is within 1/4 mile (0.4 km) of a measurement in a drill hole.

Indicated. - Coal for which estimates of the rank, quality, and quantity have been computed partly from sample analyses and measurements and partly from reasonable geologic projections. In this area, Indicated coal is the body of coal whose inner limit is 1/4 mile from a measurement in a drill hole, and whose outer limit is 3/4 mile (1.2 km) from the measurement.

Inferred. - Coal in unexplored extensions of Indicated Resources for which estimates of the quality and size are based on geologic evidence and projection. In this area, Inferred coal lies more than 3/4 mile (1.2 km) from a measurement in a drill hole, but not more than 3 miles (4.8 km).

Summary of Coal Resources

The Anderson coal bed contains estimated resources of 378 million short tons (343 million metric tons) of sub-bituminous C coal in an area of about 7200 acres (11.2 sq mi or 29 sq km), where the coal bed is at a depth of less than 200 feet (60 m), and is 26 to 33 feet (7.9 to 10.1 m) thick (Table 4 and Figure 16). Of this amount, 138 million tons (125 million metric tons) is at a depth of less than 100 feet (30 m). Most of these resources, 78%, are in the Measured and Indicated categories; the remainder is in the Inferred. About 23% of the total resources lie southeast of the main fault where the coal is more than 100 feet (30 m) deep and therefore less favorable for economic recovery.

The Dietz coal bed contains estimated resources of 55 million short tons (50 million metric tons) of sub-bituminous C coal where it is less than 200 feet (60 m) deep (Table 5 and Figure 17). Of this amount, 86% is in the Measured and Indicated categories of resources. Because it is 50 to 100 feet (15 to 30 m) below the Anderson bed and is 9 to 12 feet (2.7 to 3.7 m) thick (Figures 17 and 18), it may be economically recoverable by surface-mining methods.

In addition to depth of the coal bed, another device that is used to evaluate a surface-minable deposit of coal is the stripping ratio, which is the ratio of the volume of overburden removed per unit weight of coal recovered, usually expressed as cubic yards of overburden per short ton of coal. In the study area, the stripping ratio for coal in the Anderson bed at depths less than 100 feet (30 m) would be 2 or 2.5 to 1, depending on the recovery factor used; for Anderson coal at depths of 100-200 feet

(30-60 m) it would be about 5 to 1. Inasmuch as the Dietz coal bed cannot be surface-mined without first mining the Anderson bed, no stripping ratio is calculated for the Dietz alone. In the area where both the Anderson and Dietz are less than 200 feet (60 m) deep, the stripping ratio for the combined coal beds would be about 4 to 1.

OVERBURDEN CHEMISTRY AND MINERALOGY

(modified from USGS Open-File Report 78-393)

At potential coal mine sites in the Fort Union Coal region (where surface minable coal occurs in the Fort Union Formation) of western North America, it is necessary to determine whether there are significant quantities of materials in the overburden rock which, after disturbance and replacement, could release toxic elements to plants, grazing animals, ground water or surface drainage. This study has two goals; first, to characterize the chemical and mineralogical composition of the various types of rocks which overlie the coal at the Hanging Woman Creek study area so as to determine whether potentially harmful materials are present; the second, to predict the intensity of sampling needed at this or other similar coal mine sites to estimate with acceptable confidence the likelihood of encountering rocks in overburden that contain these potentially harmful materials.

Graphic logs of the stratigraphic columns of each of the five cored drill holes sampled for this study are presented in Figure 20.

For a discussion of areal geology, structure and stratigraphy of the Hanging Woman Creek study area, see Geology and Coal Resources Section.

Graphic stratigraphic sections (Figure 20) give the viewer an impression of the very abrupt and complete changeability of lithic types over very short vertical distances in some portions of the section, contrasted with the thick, nearly homogeneous layers of both sandstone and finer-grained rocks present in other parts of the section. An inspection of the graphical section and the map (Figure 15), shows that the strata at the Hanging Woman Creek study area, except for the coal itself and its immediately overlying fine-grained units, do not have great lateral continuity, and that there is considerable lateral thinning, interfingering and termination of units of various lithic types. The somewhat greater similarity of stratigraphic sections between holes 21 and 27 than among other pairs of more closely-spaced holes, suggests, subject to additional evidence, that the units may have greater lateral continuity north and south than in other directions. Holes 20, 21, 23, 25, and 27 correspond to holes on Figure 15 labelled K, A, H, L, and C, respectively.

Cores (size "NX") from the five holes, drilled through all overburden and the thick Anderson coal (one hole drilled deeper, through the lower Dietz coal), ranged in length from 130 to 260 feet (40 to 80 m). Holes were spaced so that the minimum and maximum distances between holes was about .62 and 2.5 miles (1 and 4 km), respectively.

Sampling Scheme and Sampling Identification Code

Four samples of each of three rock types were taken from four of the

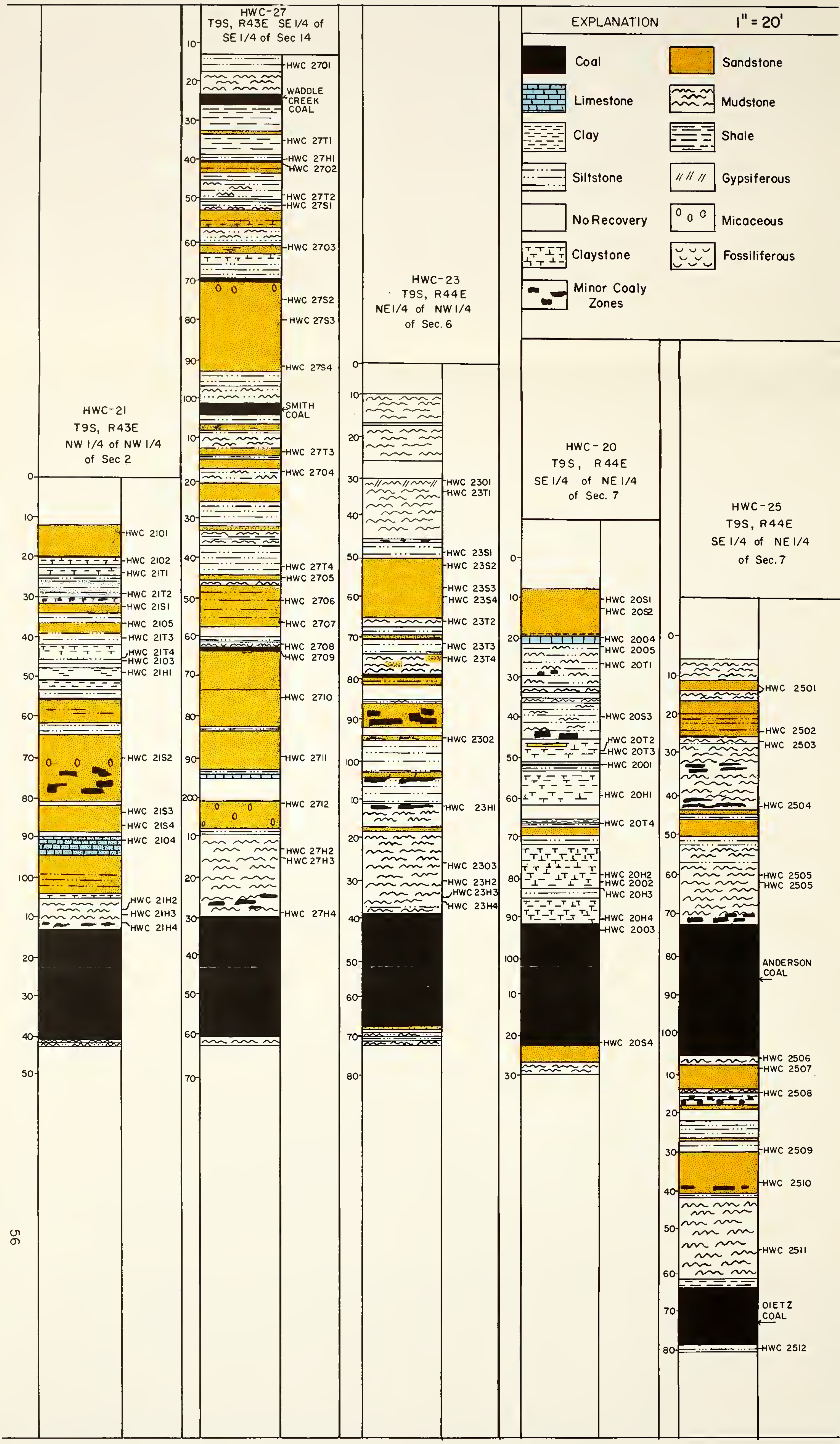


Figure 20. Graphical Stratigraphic Logs of the Cored Holes, Hanging Woman Creek Study Area
Sample Locations Are Shown by Numbers.

holes, and some "special" samples from all five holes. The following rock types were sampled:

(1) sandstone (coded "S")
(2) siltstone and shale (finer grained rocks coded "T")
(3) very dark colored or black shale (coded "H")

This classification was chosen because the three groups were expected to be chemically and mineralogically distinct. Furthermore, the chemical and mineralogical data would allow an assessment of the ability of geologists to assign correct rock names by hand specimen examination of rocks from what is, overall, a very fine-grained, inter-stratified rock sequence. We assigned names on the basis of visual inspection of the hand specimens, often in consultation with other geologists familiar with these sedimentary rocks. Footage locations for sampling the three rock types were chosen randomly. The "special" samples were taken subjectively rather than at random, and more were taken from some holes than from others.

All samples are code-labelled HWC, meaning Hanging Woman Creek, followed by four more characters: the first two identify the drill hole number (20, 21, 23, 25, or 27), the next indicate the sample type (S for sandstone, T for siltstone and shale, H for dark shale, and 0 or 1 for "specials"), and last the sequence number of that type in each hole. Thus, HWC 21H3 is the third dark shale sample from hole 21. An "x" at the very end means the sample is the analytical duplicate (split) of the sample otherwise coded the same.

The detail of illustration in the stratigraphic sections is such that the lithic type of each sample, marked by its location along the margin of the respective section, coincides plausibly with the lithic type symbolized in the illustration, whether drawn as a pure or mixed type.

Chemical and Mineralogical Analyses

Samples were analyzed in the analytical laboratories of the U.S. Geological Survey in Lakewood, Colorado. The rocks were ground to finer than 100 mesh in a ceramic mill by R. E. McGregor. Samples were analyzed by emission spectrography for Ag, As, B, Ba, Be, Cd, Ce, Co, Cr, Cu, Ga, La, Mo, Ni, Pb, Sc, Sn, Sr, V, Y. Yb, Zn, and Zr by K. E. Horan; the atomic absorption for Mg and Na by V. Merritt and for Li and Zn by J. G. Crock; by delayed neutron activation for U and Th by H. T. Millard, Jr., C. L. Shields, C. M. Ellis, R. L. Nelms, and C. A. Ramsey; by x-ray fluorescence for Al, S, Ca, Si, Fe, K, Mn, and Ti, and for Sn, Ge, As, and Se (sulfide method), by J. S. Wahlberg, W. J. Walz, J. W. Baker, and M. L. Tuttle; by gravimetry for ash content (525 degrees) by G. D. Shipley; by combustion-thermal-conductivity detection for total C, by gasometry for carbonate C, and by difference for organic C by P. H. Briggs; by wet oxidation plus atomic absorption for Hg by J. A. Thomas; and by meter for pH by G. O. Riddle.

For x-ray determination, the samples were further hand-ground in an agate motar, and the mineral composition was quantitatively determined by M. P. Pantea, using a load-packing technique and a computer method developed by L. G. Schultz to convert peak area to mineral concentration.

All samples were analyzed in a random order to neutralize effects of any systematic changes in the analytical methods.

Results

Chemical and mineralogical data are presented in a summarized graphical form in Figures 21 and 22, respectively. In these logarithmically scaled plots, an average value (geometric mean for chemistry and arithmetic mean for mineralogy) is shown for each parameter for each of the three rock types. For the chemical data (Figure 21) bars extend to higher and lower values from the central average to show the range of concentration within which 19 of 20 samples from the same rock type could be expected to fall: this range was calculated from the amount of observed variance from the average. For the mineral data, the bars represent observed ranges.

A full tabulation of the chemical and mineralogical data for each of the 108 samples (24 sandstone, 24 siltstone or shale, 23 dark shale, 37 special samples) is given in Appendix C.

The chemical and mineral data were subjected to analysis of variance in order to determine whether the largest part of the variation in the data is due to: (1) the distance between the drill holes from which the samples were taken; (2) distance between samples within the drill holes; or (3) to analytical error in the laboratory. This analysis of variance was done to estimate how many drill holes and samples for analysis would be necessary for similar studies in the future. For example, if only a small amount of the total variance in the data reflects variation among the five cored holes from which the samples are taken (that is, if samples from all holes are chemically equivalent), in future studies of areas where the subsurface geology can be reasonably well predicted, it might be economically advantageous to drill several fewer holes. As another example, if a large share of the total variance is attributable to differences among rock types and there is only small variance among all samples within that rock type, it may be possible to predict the chemistry of a rock type with acceptable confidence by visually classifying a hand specimen.

The analysis of variance must be applied individually to each element or chemical property, and it is not generally possible to estimate the variation in the body of data as a whole. However, our past experience indicates that in rocks similar to those studied here, many elements do vary together, and commonly, statements could be made about the variation of much of the entire body of data.

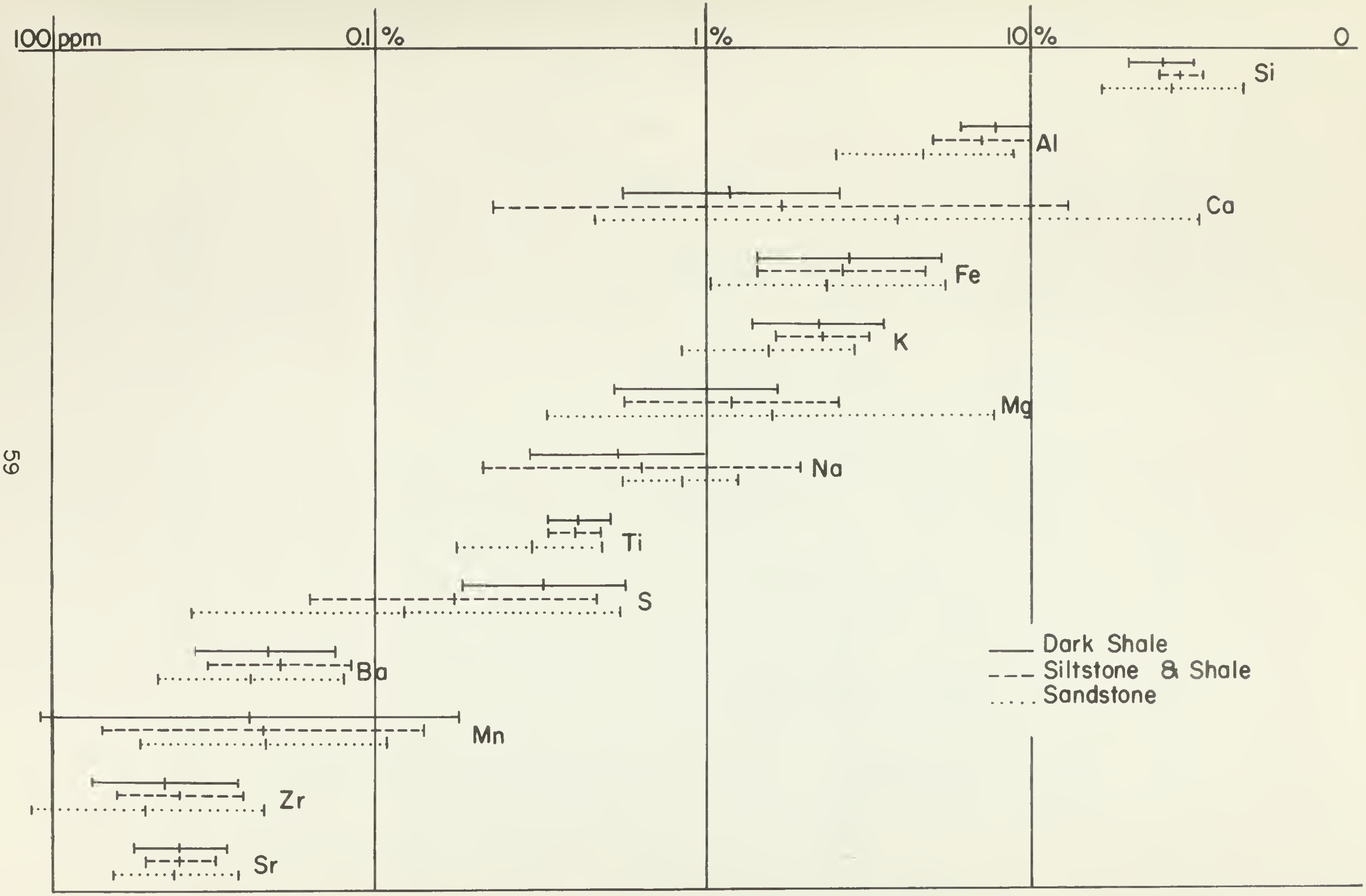
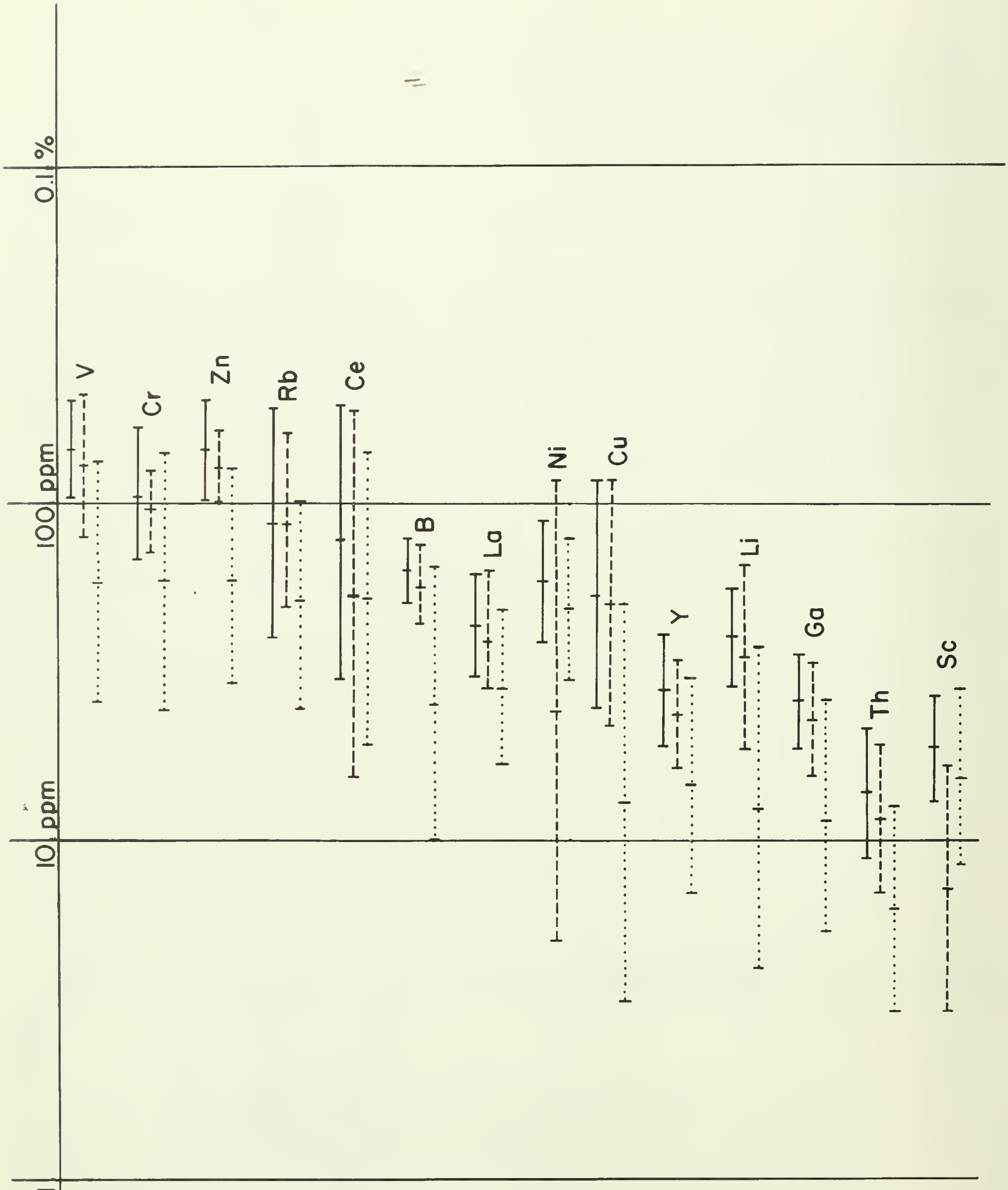
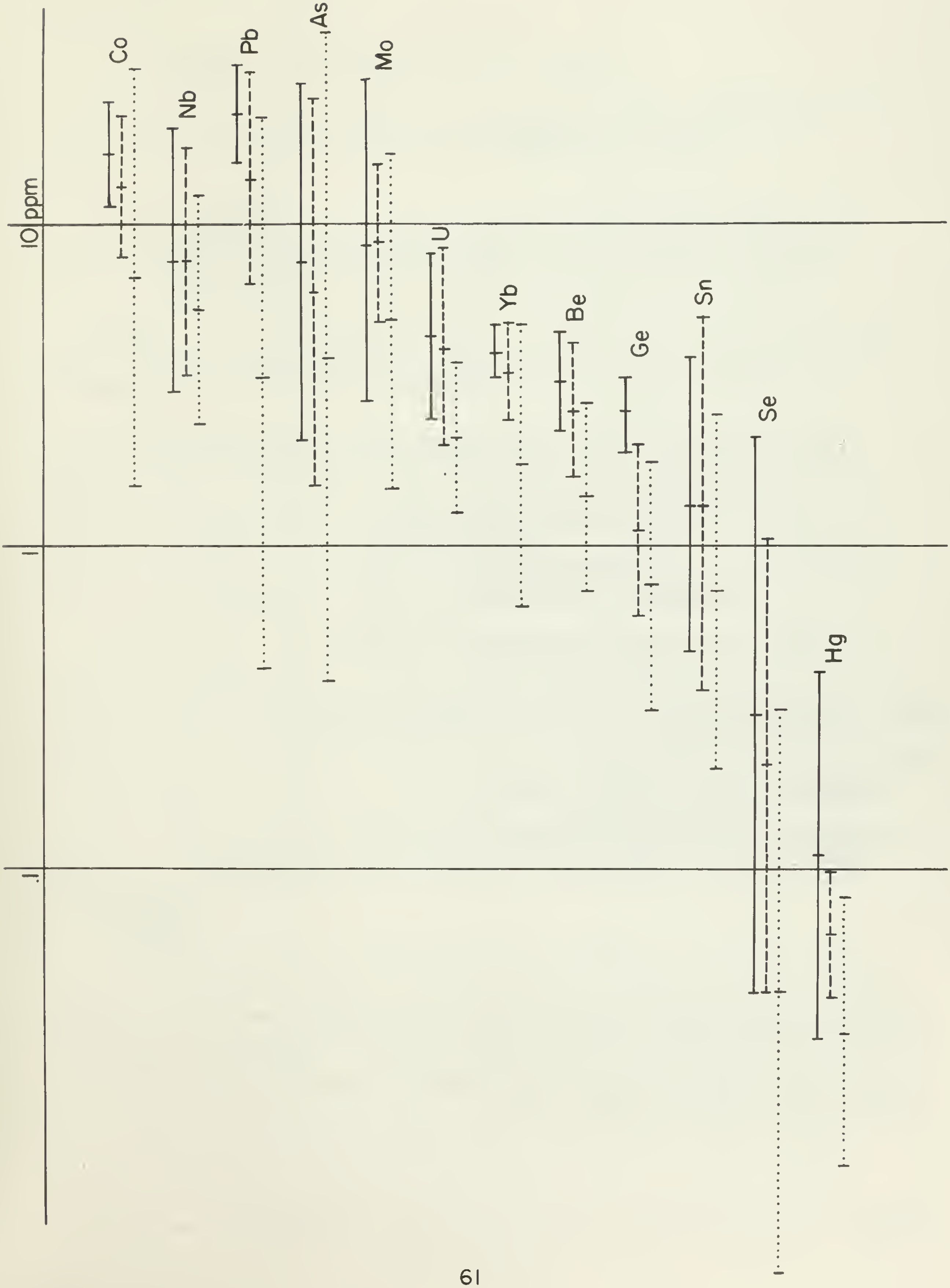


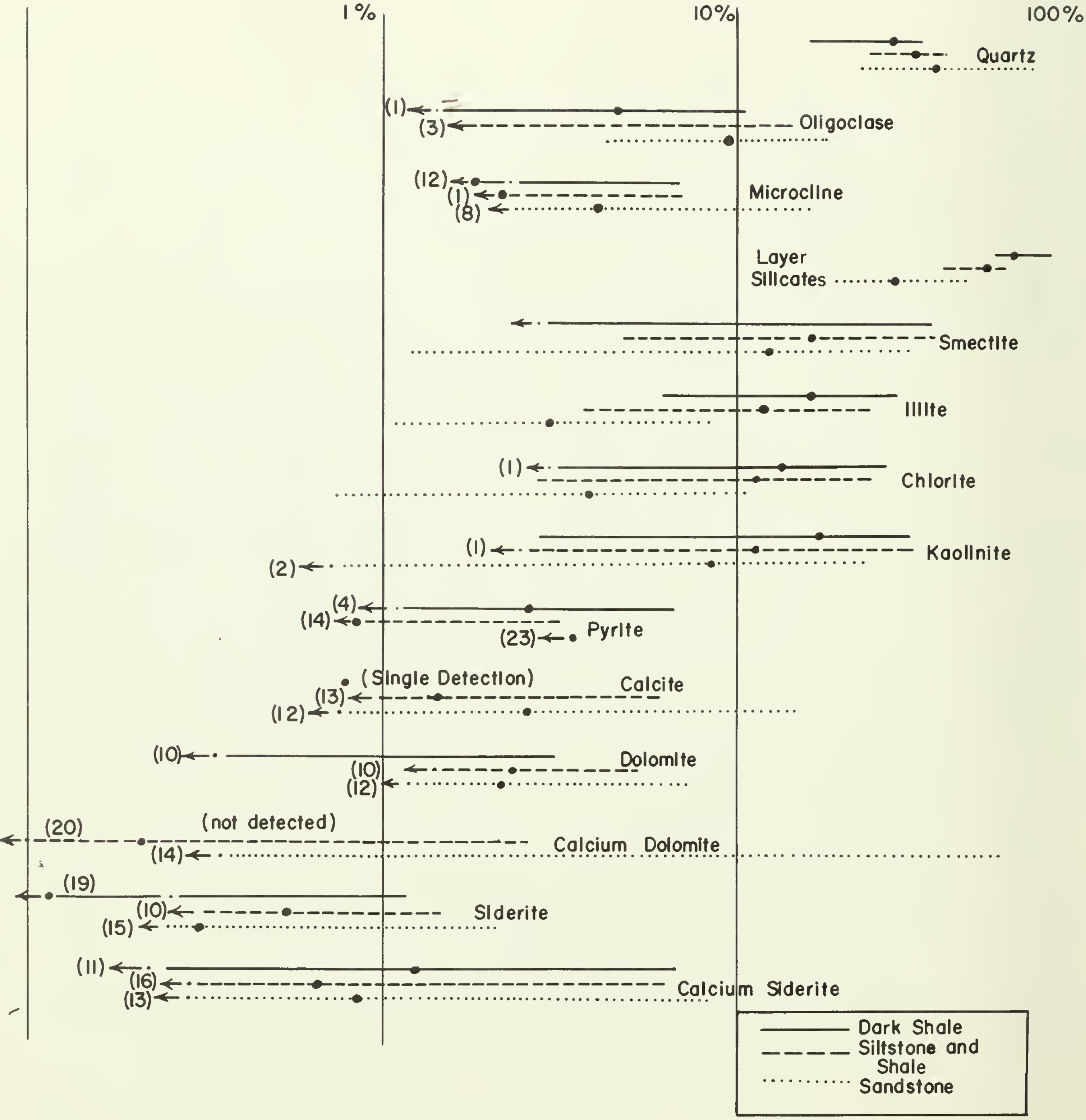
Figure 21. Averages and Expected Ranges of Elements by Rock Types, Hanging Woman Creek Site Overburden Rocks.



0.1 %
100 ppm
10 ppm
1
V
Cr
Zn
Rb
Ce
B
La
Ni
Cu
Y
Li
Ga
Th
Sc



10 ppm
1
.1
Co
Nb
Pb
As
Mo
U
Yb
Be
Ge
Sn
Se
Hg



(Central value on each bar is arithmetic average, extremes represent observed range. The number of samples in which the mineral was not detected (if any) is shown in parentheses at the left end of each plotted line; in such instances, the lowest detected value is marked as a small dot interrupting the line.

Figure 22. Averages and Ranges of Minerals by Rock Types, Hanging Woman Creek Study Area.

Discussion of Results

The first question in this study is the following: could an assessment of the Hanging Woman Creek study area overburden rock have been made with less sampling and fewer analyses? It could have been done if it is possible to answer the following two questions affirmatively:

(1) Are the chemical and mineralogical data, by rock types, constant across the study area (between the drilled holes)?
(2) Are the rocks in a single named type (sandstone; siltstone-plus-shale; dark shale) distinct and dependable in their composition?

Further on it will be discussed whether it is possible to extrapolate the sampling needs determined at this site to other sites of the Fort Union coal area.

The second question is whether there exist here in the overburden rock significant volumes of chemically or mineralogically undesirable material which should not be used as soil material on the reclaimed site. Because of the general absence of widely accepted guidelines on what constitutes "undesirable" material, a tentative answer to this question can come only from a chemical and mineralogical comparison of the rock material of this study with soil material which successfully supports the native vegetation both at this site and at other places in the region.

Table 14 presents the components of total variation within each rock type, to show whether there is much greater spread in the values of the chemical data for samples taken from many holes, drilled kilometers apart over the study site ("between holes" variance), than there would be if samples had been taken from a single drill hole ("between samples within holes" variance). The magnitude of the data in the left hand column ("total log 10 variance"), roughly correlates with the length of the bars in Figure 21 which represent the spread of concentration values for an element. The three data columns to the right of that showing variation "between cores" and "within cores" and for "laboratory error" are percentages of the total variance which is attributable to each of these three sources.

The largest share of variance for most elements is "within cores", that is between the samples taken within a single hole. The small values in the "between cores" column for most elements, indicate that the total spread of values was increased only very little by sampling from multiple holes compared to what it would have been if samples had been taken only from any one of the holes. In fact, only copper in the siltstone-plus-shale ("T" code), and magnesium and germanium in the sandstone ("S" code) showed significant variation between holes or, in other words, large differences moving across the study site. The "between holes" share of total variance for about half of the elements in all three rock types is estimated to be zero. A large share of the variance for some elements

Table 14.--Statistical summary of the chemical composition of each of three types of overburden rock (Fort Union Formation) at Hanging Woman Creek study area. Data on dry weight basis. Part A: sandstone; Part B: siltstone and shale; Part C: dark shale.

[*, indicates significance of the variance component at the 0.05 probability level; ratio is number of analyses in which element was detected in measurable amounts to total number of analyses; expected range is calculated assuming lognormal distribution of data]

Table 14. Part A: Sandstone

	Variance component as percent of total					Summary statistics					
	Total $\log_{10}$ variance	Between holes	Between samples within holes	Between analytical duplicates	Ratio	Geometric mean (ppm except as noted)	Geometric deviation	Observed range Minimum (ppm except as noted)	Observed range Maximum (ppm except as noted)	Expected range of 95 percent of samples Minimum	Expected range of 95 percent of samples Maximum
Si, percent----	0.0112	39*	60*	1	24:24	27.0	1.28	17.1	39.4	16.5	44.2
Al, percent----	.0181	0	82*	18	24:24	4.64	1.36	2.79	8.22	2.51	8.58
Ca, percent----	.213	36*	57*	7	24:24	3.87	2.89	.456	14.2	.463	32.3
Mg, percent----	.115	33	67*	<1	24:24	1.59	2.19	.294	5.08	.332	7.63
Na, percent----	.00799	18	81*	1	24:24	.84	1.23	.549	1.08	.555	1.27
K, percent-----	.0167	30	55*	15	24:24	1.55	1.35	.909	2.31	.850	2.82
Fe, percent----	.0321	0	98*	2	24:24	2.36	1.51	1.16	7.14	1.04	5.38
Ti, percent----	.0123	0	90*	10	24:24	.29	1.29	.187	.453	.174	.483
Mn, percent----	.0355	0	36	64	17:24	.0448	1.54	.0259	.100	.0189	.106
Ag-------------	.0286	16	13	71	14:24	.22	1.48	.142	.490	.100	.482
As-------------	.253	0	29	71	23:24	3.84	3.19	<.1	48.71	.38	39
B--------------	.0410	0	94*	6	24:24	25.9	1.59	11.1	48.6	10.2	65.5
Ba-------------	.0206	5	75*	20	24:24	409	1.39	256	826	211	790
Be-------------	.0210	0	89*	11	24:24	1.42	1.40	.797	2.60	.724	2.78
Ce-------------	.0467	7	0	93	24:24	52.3	1.64	22.3	101	19.4	141
Co-------------	.108	13	84*	2	24:24	6.89	2.13	1.51	15.9	1.52	31.3
Cr-------------	.0361	8	78*	14	24:24	59.4	1.55	26.9	114	24.7	143
Cu-------------	.0852	0	98*	2	24:24	13.2	1.96	5.78	62.0	3.44	50.8
F--------------	.020	0	53	47	21:24	480	1.39	<400	900	90	930
Ga-------------	.0313	0	81*	19	24:24	11.7	1.50	6.08	21.9	5.22	26.4
Ge-------------	.0361	42*	40*	18	24:24	.76	1.55	.35	1.98	.31	1.83
Hg-------------	.0436	0	58	42	24:24	.031	1.62	.02	.1	.012	.081
La-------------	.0128	0	67*	33	24:24	28.9	1.30	17.3	43.5	17.0	48.8
Li-------------	.0562	0	75*	25	23:24	12.7	1.73	3.43	2.32	4.24	38.0
Mo-------------	.0678	0	74*	26	24:24	5.02	1.82	1.98	12.5	1.52	16.6
Nb-------------	.0317	20	16	64	24:24	5.41	1.51	2.16	10.5	2.37	12.3
Ni-------------	.117	6	91*	3	24:24	24.6	2.20	5.87	70.0	5.07	119
Pb-------------	.203	1	91*	8	17:24	3.3	2.82	.793	14.8	.413	26.1
Rb-------------	.0235	26	52*	22	24:24	52.3	1.42	24.6	83.6	25.0	102
Total S, percent	.108	7	59*	34	16:24	.12	2.13	.0530	.819	.0266	.547
Sc-------------	.0329	0	78*	22	24:24	7.37	1.52	3.33	14.5	3.19	17.0
Se-------------	-	-	-	-	7:24	.042	2.74	<.1	.29	.0056	.315
Sn-------------	.0770	0	32	68	24:24	.72	1.89	.1	1.6	.202	2.57
Sr-------------	.0096	18	57*	25	24:24	240	1.25	133	389	154	374
Th-------------	.0231	0	49	51	24:24	6.33	1.42	3.38	12.58	3.14	12.8
U--------------	.0129	8	82*	10	24:24	2.17	1.30	1.55	3.41	1.28	3.7
V--------------	.0307	0	95*	5	24:24	59.0	1.50	32.7	106	26.2	133
Y--------------	.0254	19	35	46	24:24	14.7	1.44	8.03	28.0	7.07	30.4
Yb-------------	.0485	12	15	73	24:24	1.79	1.66	.68	3.4	.65	4.9
Zn-------------	.0236	0	100*	<1	24:24	59.7	1.42	31	101	29.9	128
Zr-------------	.0324	11	27	62	24:24	196	1.51	84.7	428	85.8	446
Total C, percent	.117	15	85*	<.1	24:24	2.11	2.19	.38	6.35	.44	10.1
Organic C, percent------	.189	12	2	87	24:24	.41	2.72	.03	2.4	.055	3.03
Carbonate C, percent------	.246	29	69*	1	24:24	1.26	3.13	.13	6.05	.129	12.3
Ash, percent---	2.847[1/]	0	61	39	24:24	96.4[2/]	1.69[3/]	92.3	98.4		
pH-------------	.442[1/]	0	95*	5	24:24	8.95[2/]	.66[3/]	7	10		

1/ Total variance.

2/ Arithmetic mean.

3/ Standard deviation.

Table 14. Part B: Siltstone and shale

	Total $\log_{10}$ variance	Variance component as percent of total: Between holes	Between samples within holes	Between analytical duplicates	Ratio	Summary statistics: Geometric mean (ppm except as noted)	Geometric deviation	Observed range: Minimum (ppm except as noted)	Maximum	Expected range of 95 percent of samples: Minimum	Maximum
Si, percent------	0.00117	0	91*	9	24:24	28.8	1.08	25.2	31.5	24.6	33.5
Al, percent------	.00559	0	96*	4	24:24	7.01	1.19	5.14	8.81	4.95	9.93
Ca, percent------	.192	0	>99*	<1	24:24	1.71	2.75	.437	5.83	.226	12.9
Mg, percent------	.0272	0	>99*	<1	24:24	1.20	1.46	.671	1.75	.563	2.56
Na, percent------	.0595	3	96*	1	24:24	.64	1.75	.124	.978	.209	1.96
K, percent-------	.00491	0	96*	4	24:24	2.28	1.18	1.50	3.00	1.64	3.17
Fe, percent------	.0164	0	99*	1	24:24	2.62	1.34	1.96	5.36	1.46	4.71
Ti, percent------	.0017	0	94*	6	24:24	.40	1.10	.318	.447	.331	.484
Mn, percent------	.0606	0	92*	8	15:24	.0446	1.76	.0254	.125	.0144	.138
Ag---------------	.0234	0	65*	35	23:24	.38	1.42	.148	.802	.188	.766
As---------------	.0888	0	80*	20	24:24	6.10	1.99	2.67	62.2	1.54	24.2
B----------------	.0034	0	81*	19	24:24	57.8	1.14	43.9	69.8	44.5	75.1
Ba---------------	.012	<1	71*	29	24:24	503	1.29	336	880	302	837
Be---------------	.0111	0	86*	14	24:24	2.61	1.27	1.70	3.55	1.62	4.21
Ce---------------	.0730	23*	0	77	22:23	54.2	1.86	14.2	115	15.7	187
Co---------------	.0121	0	86*	14	24:24	13.0	1.29	7.43	18.9	7.83	21.7
Cr---------------	.00372	11	53	36	24:24	96.1	1.15	68.1	126	72.6	127
Cu---------------	.0335	52*	23	25	24:24	51.3	1.52	18.7	80.4	22.2	118
F----------------	.0159	0	0	100	23:24	.077	1.34	<.04	.1	.0429	.138
Ga---------------	.00704	0	77*	23	24:24	23.2	1.21	16.5	33.9	15.8	34.0
Ge---------------	.0181	0	57	43	24:24	1.12	1.36	.576	1.74	.606	2.07
Hg---------------	.00915	0	60	40	24:24	.063	1.25	.04	.09	.0403	.0984
La---------------	.00440	19	17	64	24:24	39	1.17	28.9	55.6	28.5	53.4
Li---------------	.0186	0	91*	9	24:24	35.3	1.37	20.1	56.3	18.8	66.3
Mo---------------	.0147	10	0	90	24:24	8.67	1.32	5.20	14.0	4.98	15.1
Nb---------------	.0308	0	45	55	24:24	7.66	1.50	4.21	17.9	3.40	17.2
Ni---------------	.0110	1	88*	12	24:24	49.0	1.27	33.1	67.6	30.4	79.1
Pb---------------	.0266	8	75*	18	24:24	13.9	1.46	6.00	24.7	6.52	29.6
Rb---------------	.0164	0	35	65	24:24	89.6	1.34	51.1	129	49.9	161
Total S, percent-	.0480	1	68*	31	23:24	.17	1.66	.0538	.402	.0617	.468
Sc---------------	.0159	5	71*	24	24:24	15.7	1.34	9.18	26.5	8.76	28.2
Se---------------	.123	6	0	94	19:24	.21	2.24	<.1	.790	.0419	1.05
Sn---------------	.0826	0	44	56	24:24	1.33	1.94	.15	2.32	.353	5.01
Sr---------------	.00276	1	48	55	24:24	249	1.13	189	330	195.1	318
Th---------------	.0119	5	28	68	24:24	11.7	1.29	7.19	21.7	7.03	19.5
U----------------	.0235	0	72*	28	24:24	4.14	1.42	2.91	7.75	2.05	8.35
V----------------	.0117	0	72*	28	24:24	131	1.28	85.4	186	79.9	215
Y----------------	.00621	2	43	56	24:24	23.8	1.20	16.8	32.7	76.5	34.2
Yb---------------	.00570	0	65*	35	24:24	3.45	1.19	2.45	4.52	2.44	4.89
Zn---------------	.00413	0	90*	10	24:24	110.	1.16	86.2	146	81.8	148
Zr---------------	.00926	2	45	53	24:24	248	1.25	140	327	159	388
Total C, percent-	.0416	1	98*	<1	24:24	1.39	1.60	.68	2.48	.543	3.56
Organic C, percent	.0129	0	64*	36	24:24	.85	1.30	.55	1.39	.503	1.44
Carbonate C, percent--------	1.16	0	78*	22	17:24	.11	12	<.01	1.58	.000707	1.57
Ash, percent-----	1.35[1]	9	13	77	24:24	95.2[2]	1.16[3]	93.1	98.1		
pH---------------	1.09[1]	2	94*	4	24:24	8.08[2]	1.04[3]	5.1	9.1		

[1] Total variance.

[2] Arithmetic mean.

[3] Standard deviation.

Table 14. Part C: Dark Shale

	Variance component as percent of total					Summary statistics					
	Total $\log_{10}$ variance	Between holes	Between samples within holes	Between analytical duplicates	Ratio	Geometric mean (ppm except as noted)	Geometric deviation	Observed range (ppm except as noted) Minimum	Observed range Maximum	Expected range of 95 percent of samples Minimum	Expected range of 95 percent of samples Maximum
Si, percent--------	0.00224	0	98*	2	23:23	25.1	1.12	18.2	27.7	20.0	31.4
Al, percent--------	.00302	0	79*	21	23:23	7.79	1.13	6.08	9.73	6.10	9.95
Ca, percent--------	.0279	6	0	94	23:23	1.19	1.47	.70	4.37	.55	2.57
Mg, percent--------	.0152	7	92*	<1	23:23	.94	1.33	.48	1.29	.53	1.66
Na, percent--------	.0182	22	77*	1	23:23	.54	1.36	.18	.79	.29	1.00
K, percent---------	.0101	0	91*	9	23:23	2.21	1.26	1.09	2.71	1.39	3 50
Fe, percent--------	.0192	0	98*	2	23:23	2.75	1.38	1.44	4.99	1.45	5.24
Ti, percent--------	.00191	0	87*	13	23:23	.41	1.11	.34	.46	.33	.51
Mn, percent--------	.104	18	71*	12	11:23	.0402	2.10	.0165	.168	.00912	.177
Ag-----------------	.0545	0	0	100	20:23	.35	1.71	.12	.54	.12	1.02
As-----------------	.0768	0	4	96	23:23	7.58	1.89	1.71	27.43	2.12	27.1
B------------------	.00219	22	20	58	23:23	63.9	1.11	50.0	76.5	51.9	78.7
Ba-----------------	.011	7	46	46	23:23	453	1.28	240	655	276	741
Be-----------------	.00635	0	49	51	23:23	3.21	1.20	2.11	5.05	2.23	4.62
Ce-----------------	.0397	0	65*	35	22:22	78.6	1.58	43.8	167	31.5	196
Co-----------------	.00640	0	91*	9	23:23	16.4	1.20	11.8	20.9	11.4	23.7
Cr-----------------	.00967	5	87*	8	23:23	109	1.25	66.2	252	69.8	170
Cu-----------------	.0286	0	22	78	22:22	54.0	1.48	18.2	93.6	24.7	118
F------------------	.00937	0	53	47	23:23	.08	1.26	.05	.11	.050	.127
Ga-----------------	.00471	3	68*	29	23:23	26.2	1.17	17.4	35.9	19.1	35.9
Ge-----------------	.0319	0	35	65	23:23	1.30	1.51	.531	2.49	.570	2.96
Hg-----------------	.0797	0	98*	2	23:23	.11	1.92	.04	.44	.0298	.406
La-----------------	.00546	0	53	47	23:23	43.6	1.19	28.7	59.5	30.8	61.7
Li-----------------	.00501	0	0	100	23:23	40.8	1.18	31.8	51.0	29.3	56.8
Mo-----------------	.0618	0	0	100	23:23	8.54	1.77	1.13	19.4	2.82	27.7
Nb-----------------	.0441	0	21	79	23:23	7.54	1.62	3.22	18.3	2.87	19.8
Ni-----------------	.00821	0	85*	15	23:23	58.5	1.23	37.1	77.8	38.7	88.6
Pb-----------------	.00563	<1	78*	21	23:23	21.9	1.19	16.6	36.6	15.5	31.0
Rb-----------------	.0283	18	70*	12	23:23	88.3	1.47	33.0	135	40.6	191
Total S, percent---	.0155	0	23	77	23:23	.32	1.33	.17	.52	.18	.57
Sc-----------------	.00626	0	76*	24	23:23	19.1	1.20	12.8	24.4	13.3	27.6
Se-----------------	.186	0	0	100	20:23	.30	2.70	<.1	.994	.0412	2.19
Sn-----------------	.0517	10	<1	89	23:23	1.34	1.69	.424	2.40	.469	3.83
Sr-----------------	.00531	0	81*	19	23:23	24.6	1.18	184	315	179	342
Th-----------------	.00958	4	75*	22	23:23	14.1	1.25	9.63	23.1	9.00	22.0
U------------------	.0160	10	87*	3	23:23	4.47	1.34	3.49	11.4	2.49	8.03
V------------------	.00447	0	75*	25	23:23	148	1.17	105	192	107	202
Y------------------	.00793	9	0	91	23:23	28.2	1.23	22.1	40.7	18.6	42.6
Yb-----------------	.00175	0	28	72	23:23	4.00	1.10	3.39	4.77	3.31	4.84
Zn-----------------	.00453	0	99*	1	23:23	125	1.17	79.5	143	91.6	172
Zr-----------------	.0132	0	68*	32	23:23	221	1.30	142	352	131	383
Total C, percent---	.0846	1	99*	<1	23:23	5.60	1.95	2.54	24.89	1.47	21.3
Organic C, percent-	.219	0	37	63	23:23	4.60	2.94	.18	24.89	.532	39.8
Carbonate C, percent	.622	0	37	63	17:23	.07	6.15	<.01	.77	.00185	2.65
Ash, percent-------	75.5[1]	0	100*	<1	23:23	85.4[2]	8.69[3]	60.7	91.9		
pH-----------------	.641[1]	21	76*	3	23:23	7.66[2]	.8[3]	5.4	8.4		

[1] Total variance.

[2] Arithmetic mean.

[3] Standard deviation.

which are present in low concentration or which are difficult to measure appears in the "laboratory error" column, and represents the differences in reported values of samples which were physically divided in half and the "splits" submitted separately to the laboratory.

The distribution of the three components of total variance discussed above shows clearly that very nearly as much information about the range in composition of the Hanging Woman rocks could have been obtained if only a single hole had been drilled: there would have been only a very slight risk of missing rocks of unusual character if drilling the other holes had been omitted.

Chemical Distinctiveness of the Three Rock Types

The three ternary plots of Figure 23 show that there is a general chemical separation of the three rock types, but with considerable overlap (see also Table 14 and Figure 21). The eight trace elements (top corners of the plots) tend to be more abundant in dark shale and siltstone-plus-shale than they are in sandstone, but the dark shale is only somewhat higher in these elements than the siltstone-plus-shale.

Sandstone and siltstone-plus-shale samples have compositions indicating that both rock types contain a mixture of quartz and feldspar grains. In a sedimentation environment where greater amounts of energy had been available, it might be expected that the two minerals would be separated by mechanical winnowing and segragated into characteristic size ranges. However, in the relatively low-energy environment of the deposition of the Fort Union sediments both quartz and feldspar grains of all sizes were dumped in the basin and neither sufficient mechanical energy nor time for extensive weathering were available to alter the original, mixed compositional relationships. It may be tentatively assumed that the feldspar-rich Fort Union, if used as soil material, would be better able to provide minor and trace elements necessary to plants than would more quartz-rich sandstone common in other regions. Feldspars contain major amounts of calcium and potassium, which are essential to plants, and of aluminum, the key constituent of clay minerals formed during weathering which hold and release plant nutrients. Feldspars also contain a broad range of minor and trace elements to be released during weathering or alteration. Quartz, by contrast, is almost barren of all elements except silicon and oxygen, is almost immune to breakdown, and its surfaces play almost no role in exchange or release of elements in soil.

The overlap in chemical composition between dark shale and siltstone-plus-shale is consistent with the fact that the two types of shale exist in continuous variation in the cores, commonly changing over small vertical distances, and the two types cannot properly be differentiated at the scale of the illustrated sections presented in Figure 20. Mineralogical data for the three rock types is presented in Table 15.

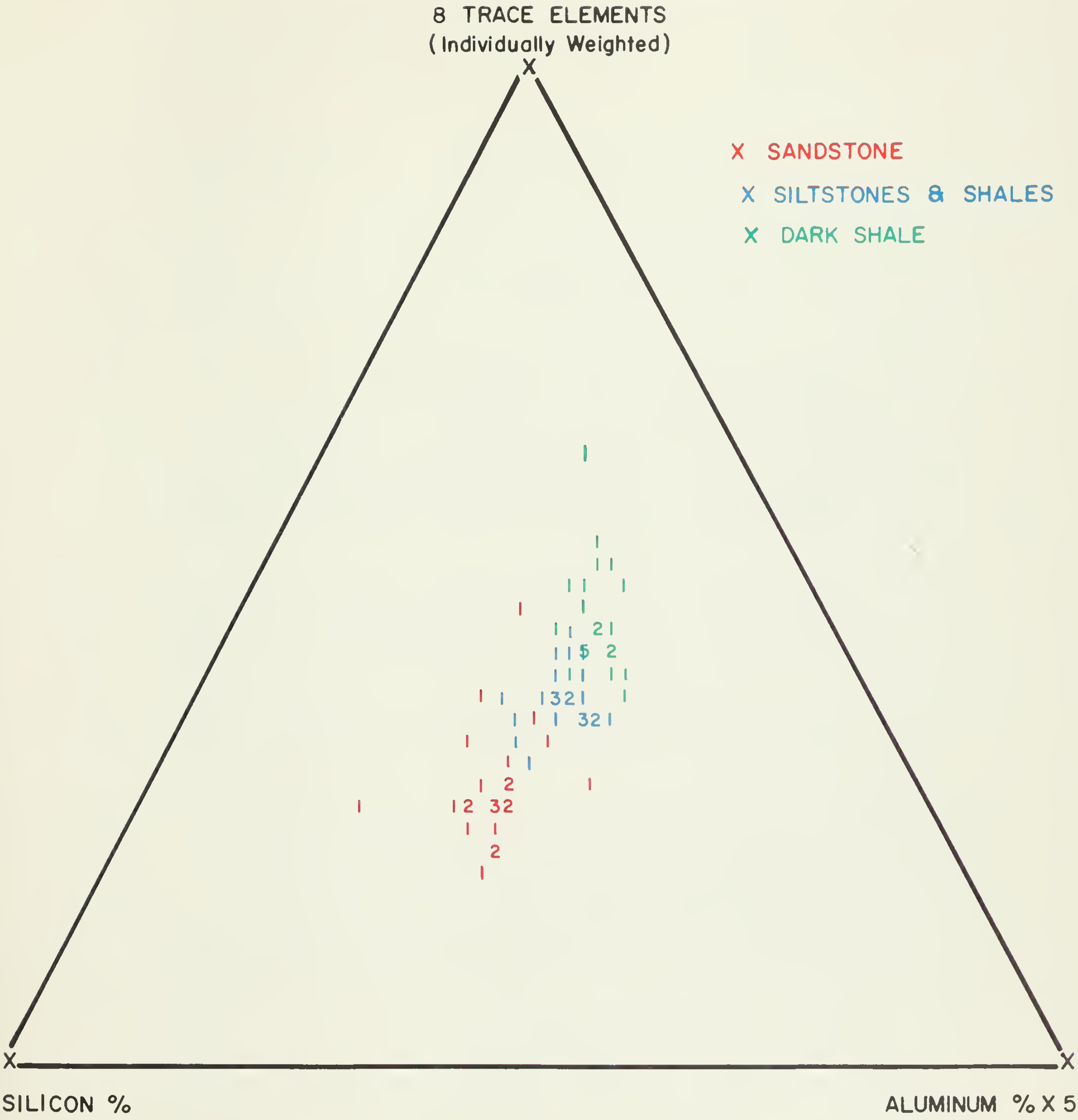


Figure 23.

Compositional relationships of the samples of the three rock types with respect to silicon, aluminum and a suite of eight trace elements. The digits indicate the number of samples which plot at that point. The trace elements (beryllium, copper, lanthanum, lead, mercury, nickel, sulfur and yttrium) have been weighted in inverse relation to their typical concentrations, so each will have an equal effect on the plot.

Table 15. Statistical summary of mineral composition of the three rock types

[Data in percent. Ratio is number of analyses in which mineral was detected to total number of samples analyzed]

Mineral	Sandstone				Siltstones plus shale				Dark shale			
	Ratio	Arithmetic mean	Standard deviation	Observed range	Ratio	Arithmetic mean	Standard deviation	Observed range	Ratio	Arithmetic mean	Standard deviation	Observed range
Quartz----------	24:24	37.2	11.9	22.5-70.9	24:24	32.6	4.50	24.0-39.6	23:23	27.5	3.29	16.1-31.7
Oligoclase------	24:24	9.59	3.01	4.30-17.6	21:24	7.37	4.36	0-14.1	22:23	4.58	2.81	0-10.2
Microcline------	16:24	4.08	4.29	0-16.0	13:24	2.19	2.32	0-6.97	11:23	1.85	2.08	0-6.87
Layer silicates-	24:24	28.0	10.2	10.9-44.1	24:24	51.7	7.29	38.3-65.5	23:23	60.7	5.46	53.7-78.4
Calcite---------	12:24	2.53	4.86	0-19.1	11:24	1.46	1.80	0-5.54	1:23	-	-	0-0.78
Mg-calcite------	1:24	-	-	0-.87	2:24	-	-	0-1.43	0:23	0	-	-
Dolomite--------	12:24	2.19	2.52	0-7.07	14:24	2.33	2.27	0-6.23	13:23	1.01	.731	0-2.09
Ca-dolomite-----	10:24	14.4	20.9	0-55.6	4:24	.214	.637	0-2.56	0:23	0	-	-
Siderite--------	9:24	.301	.531	0-2.07	14:24	.447	.476	0-1.46	4:23	.117	.286	0- 22
Ca-siderite-----	11:24	.887	1.80	0-8.18	8:24	.679	1.49	0-6.38	12:23	1.29	1.75	0-6.80
Pyrite----------	1:24	-	-	0-3.49	10:24	.878	1.13	0-3.33	19:23	2.63	1.85	0-6.79
Marcasite-------	1:24	-	-	0-10.0	0:24	0	-	-	0:23	0	-	-
Gypsum----------	1:24	-	-	0-5.87	0:24	0	-	-	1:23	-	-	0-4.61
Smectite--------	24:24	12.6	8.02	1.22-31.0	24:24	16.5	7.67	4.83-36.0	20:23	14.6	12.5	0-35.3
Illite----------	24:24	2.97	1.67	1.10-8.16	24:24	12.0	6.72	3.83-24.5	23:23	15.1	6.42	6.13-26.8
Chlorite--------	23:24	3.79	2.48	.74-10.2	24:24	11.4	6.94	2.73-24.5	22:23	13.5	9.50	0-26.8
Kaolinite-------	22:24	8.53	7.08	0-22.9	23:24	11.6	8.38	0-32.6	23:23	17.3	8.08	2.78-31.3

"Special Samples"

The samples not classified as members of any of the three rock-type groups were chosen subjectively, because they looked interesting or different, or in many cases because they represented a type of rock seen repeatedly up and down the section, though not commonly in great volume abundance. Many of these "special" samples, despite somewhat anomalous appearance, fit with good chemical and mineralogical conformity into one of the three main rock type classes of this study. On the other hand, the "special" samples commonly have the highest concentrations of certain suites of elements, and commonly have a distinctive mineralogy, which set them apart from the three rock types.

Some significant features of the "special" samples are the following:

(1) The samples with the highest concentrations of minor and trace elements are dark in color and similar to dark shale ("H" code samples). Of the three rocks, such dark shale is the most undesirable reclamation potential.
(2) These dark samples commonly are close to the coal beds.
(3) Other types of "specials", distinct by their chemistry, minerology or texture, are present in small volume abundance and for this reason do not generally represent a clear chemical threat in reclamation work. The strata in which they occur are most commonly too thin to be handled separately during excavation procedures.

Of the "special" samples the dark, shaly or coaly rocks with high trace-element and pyrite concentrations, which promote acidity and element mobilization during weathering, may be close to either major coal beds or thinner coaly zones. Examples are HWC 2103, 2504, 2702, and 2708, which may be found catalogued chemically and mineralogically in the large table in Appendix C. A general recommendation may be made that entire strata (coal bed boundary zones and thin, low-grade coaly layers) containing such rocks be segregated for reburial away from soil and ground-water zones, wherever practical or where sufficient volumes exist to preclude acceptable dilution by larger volumes of sandy rocks.

Conspicuous rocks of other types that deserve mention constitute thin, hard strata interrupting thicker zones of soft gray or tan mudstones or sandstone. These rocks are largely mixed carbonates of two types: a hard tan rock appearing as siltstone, which is 45-60% calcian siderite ($[Fe, Ca]CO_3$) (examples are HWC 2001, 2302, 2500); and a hard gray or blue rock appearing as siltstone or sandstone which is 25-60% magnesian calcite (examples are HWC 2004, 2104, and 2707). Such rocks do not have high concentrations of minor and trace elements.

Similarity of Rocks at Hanging Woman Creek Study Area To Rocks Elsewhere in the Fort Union Coal Region

Table 16 presents concentrations of selected elements in the three types of rocks at the Hanging Woman Creek study area (3 left-hand columns)

Table 16.--Selected elements in three Hanging Woman Creek study area rock types, (Fort Union Formation), compared to Fort Union rocks and soils from other locations in and near the Fort Union coal region.

[Values are geometric means, or arithmetic averages of geometric means of subgroups. All data reported on dry weight basis. N.R., no reported]

	Hanging Woman Creek Rocks, This Study			Rocks from outcrop Ebens & McNeal, 1977 (80 samples each type)		Fine-grained rocks, from cores, Hinkley & Ebens, 1977 (50 samples)	C-horizon soils Hanging Woman Site, Tidball, 1978	C-horizon soils, Powder River Basin, Tidball & Ebens, 1976	Subsoils of Powder River Basin, Connor, Keith & Anderson, 1976
	Sandstone	Siltstone and shale	Dark shale	Sandstone	Shale				
As------	3.8	6.1	7.6	4.4	5.1	3.6	7.3	N.R.	N.R.
B-------	26	58	64	51	98	59	41	24 1/	26
Co------	6.9	13	16	5.4	9.1	8.7	9.5 1/	7.3	6.3
Cr------	59	96	109	45	84	72	59 1/	46	49
Cu------	13	51	54	13	34	38	35 1/	17	16
Hg------	.031	.063	.11	.032	.060	.10	.03	N.R.	.023
Mo------	5.0	8.7	8.5	5.0	8.1	6.1	N.R.	N.R.	<3
Na------	.84	.64	.54	.49	.42	.64	.72	.47	N.R.
Pb------	3.3	13.9	22	5.2	15	11	N.R.	N.R.	17
Se------	.042	.21	.30	.19	N.R.	.16	N.R.	N.R.	N.R.
V-------	59	131	148	46	97	86	N.R.	N.R.	87
Zn------	60	110	125	44	80	100	N.R.	N.R.	61

1/ Averaged from values for distinct soil types or regions.

for comparison with sandstone and fine-grained rocks of the Fort Union Formation of the Northern Great Plains (next three columns). The values for these other Fort Union area rocks are averages (geometric means) of 80 samples of the sandstone and shale from outcrop and 50 samples of the fine-grained rocks from cores. In all three studies taken as a whole, the rock samples were collected from many sites spread over an area hundreds of kilometers wide. Analytical and preparation procedures were identical in all three studies. Comparison of the data among the three studies shows clearly that the values of the sandstone and siltstone-plus-shale in this study are quite similar to corresponding rock types of the Fort Union Formation from other areas in the region. Possible exceptions are that sandstone from the Hanging Woman Creek study area has noticeably lower boron and selenium concentrations and higher sodium concentrations than the outcrop rocks of the Ebens and McNeal study (1977) with which comparison might be made; and selenium concentrations appear to be larger in Hanging Woman fine-grained rocks from the Hanging Woman Creek study area than in those of the Hinkley and Ebens study (1977). It is clear that the average chemical values of rocks at the Hanging Woman Creek study area are representative of the area in general.

In addition to having similar average values of elemental composition, the rocks at the Hanging Woman Creek study area and the rocks of the broader region also have similar degrees of spread (total variance) about their average values and a similar pattern of chemical variation with respect to spatial location of the samples. This can be seen by comparing the values, between studies, of total variance and individual components of variance ("between holes" and "between samples within holes"; these values are not given here for the other studies listed in Table 16, so the reader must consult them directly). These similarities strongly indicate that, just as at the Hanging Woman Creek study area, most of the chemical information about the rocks at other sites could have been obtained from a sampling and analysis program much less extensive than the one followed in this study.

Comparison of Outcrop and Drilled Core Samples

In Table 16, the chemical values for sandstone and shale collected from outcrop (Ebens and McNeal, 1977) are very close to the values for the corresponding rock types sampled from core in both the Hanging Woman Creek study area and the 5-site study of Hinkley and Ebens (1977), (fifth column of the table).

Samples in both the Ebens and McNeal outcrop study and Hinkley and Ebens core study were taken over wide areas and represent large numbers of samples; moreover, the analytical methods used were identical to those used in this study. The similarity suggests strongly that in potential mining sites where the overburden material is exposed as outcrop within or near the area to be disturbed, at least some samples may be collected from the outcrop for lithologic classification and possible chemical analysis with confidence that the results will be similar to results from the more expensive core samples.

Summary

Generally, the dark shale contains the largest concentrations of trace elements and sandstone the smallest (Figure 21). This is to be expected on the basis of nearly all reports on the geochemistry of earth materials over the last several decades. For the major elements the distribution among the rock types is due to their mineralogical composition; calcium and sodium are highest in sandstone and lowest in dark shale, because of the abundance of Ca and Na feldspars in these arkosic sandstones (i.e., sandstones with a high feldspar content); aluminum is highest in minerals in the shale; iron is highest in the dark shale probably because the reducing chemical environment of its deposition favored its precipitation.

Sandstone generally has the widest spread in its chemical data. This is due to the fact that despite the visible presence of the sand-size grains (both quartz and feldspar) in these rocks, the remainder of the material which they contain may be mineralogically very varied and may include much or little clay. This fact emphasizes the need for using the greatest possible care in inspection before classifying a rock of the Fort Union Formation as a sandstone, to be sure that it is not simply an unstructured slightly gritty rock of another class with a large fraction or layer of silicate (clay) minerals and high concentrations of minor and trace elements.

The recommendation made here for a limited amount of sampling and analysis of overburden in the Fort Union region is based on our finding that the rock material is homogeneous, and that the concentrations of potentially harmful elements are not high. We feel that it is not justifiable to spend large amounts of money for a slight increase in the confidence that minor zones of high concentration have not escaped detection. However, in other types of studies, such as searches for small-volume, economically valuable mineral deposits, much more extensive sampling and analysis might be clearly justifiable.

SOILS

Two Soil Conservation Service soil surveys cover the area delineated as the Hanging Woman Creek study area; Powder River County Soil Survey and Big Horn County Soil Survey (USDA, SCS Soil Survey Staff, 1971, 1977). The soils map (Figure 24) delineates the soil mapping units for the entire area. A detailed study was done on the soils of the known strippable coal area . This study is contained in the section "Soil Chemistry and Mineralogy".

Each mapping unit was measured and acreages of each calculated. This involved the East Trail Creek drainage. Acreages of each soil series and phase within each mapping unit were calculated and their proportional extents were tabulated (Table 17).

Soils in this study area lie upon landscapes ranging from undulating gentle slopes to hilly and steep topography. Soils on the undulating gentle slopes are primarily Thedalund loam and Thurlow silty clay loam. These are deep loamy soils and cover 40% of the study area. They developed primarily from soft sandstone. The predominant soil on the hilly and steeper topography is the Midway silty clay loam. This shallow soil, overlying shale, is typical of those covering the steeper land. Midway occupies over 25% of the area.

For complete descriptions of the soil mapping units in the entire area consult the two published soil surveys.

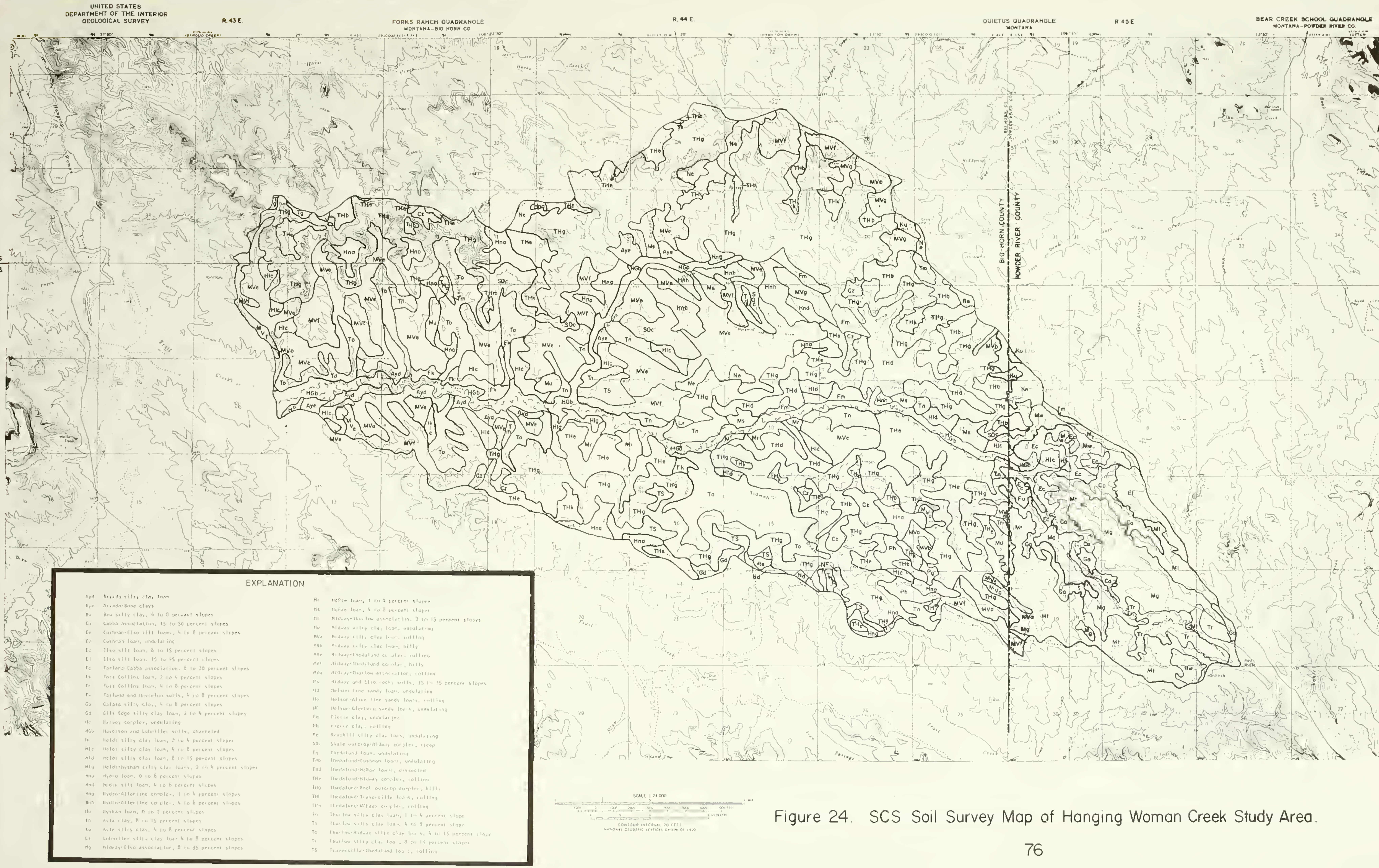


Figure 24. SCS Soil Survey Map of Hanging Woman Creek Study Area.

Table 17. Hanging Woman Creek study area soil mapping acreages.

Mapping Unit/Components	Mapping Unit Acres	Mapping Unit Percent of Total Area	Component Percent of Mapping Unit	Component Acres	1/ Topsoil Depth in Inches	2/ Hydrologic Soil Group
(Ayd) Arvada silty clay loam	94	0.88%				
Arvada sicl			90%	175	3"	D
Bone c			10%	19	0" 3/	D
(Aye) Arvada-Bone clays	105	0.48%				
Arvada c			70%	74	3"	D
Bone c			20%	21	0" 3/	D
Hydro sicl			10%	10	10"	C/D
(Bw) Bew silty clay 4 to 8 percent slopes	49	0.22%				
Bew sic			95%	47	0" 3/	D
Thurlow, Hesper, Hydro			5%	2	10-60" 4/	-
(Ca) Cabba association 5 to 15 percent slopes	375	1.7%				
Cabba sil			45%	169	16"	C
Cabba cl			40%	150	16"	C
Midway cl			15%	56	3"	D
(Cz) Cushman loam, undulating	200	0.91%				
Cushman l			95%	190	24"	C
Heldt sicl			1%	2	6"	C
Midway sicl			2%	4	3"	D
Thurlow sicl			2%	4	60" 4/	D

Table 17. Hanging Woman Creek study area soil mapping acreages.--continued

Mapping Unit/Components	Mapping Unit Acres	Mapping Unit Percent of Total Area	Component Percent of Mapping Unit	Component Acres	1/ Topsoil Depth in Inches	2/ Hydrologic Soil Group
(Ce) Cushman-Elso silt loams, 4 to 8 percent slopes	29	0.14%				
Cushman sil			65%	18	24"	C
Elso sil			30%	9	20"	C
Fort Collins, Thurlow, McRae			5%	1	60" 4/	-
(Ec) Elso silt loam, 8 to 15 percent slopes	232	1.1%				
Elso sil			95%	221	20"	C
Thurlow, Fort Collins, Remmit			5%	11 11	60" _/	-
(El) Elso silt loam, 15 to 45 percent slopes	105	0.48%				
Elso sil			95%	99	20"	C
Thurlow, Fort Collins, Remmit			5%	6	60" 4/	-
(Fc) Farland-Cabba association 8 to 20 percent slopes	23	0.10%				
Farland sil			70%	16	60" 4/	C
Cabba sil			30%	7	16"	C
(Fx) Farland and Havrelon soils 4 to 8 percent slopes	47	0.21%				
Farland sil			varies -		60" 4/	C
Havrelon sil			undifferentiated group		60" 4/	B

Table 17. Hanging Woman Creek study area soil mapping acreages.--continued

Mapping Unit/Components	Mapping Unit Acres	Mapping Unit Percent of Total Area	Component Percent of Mapping Unit	Component Acres	1/ Topsoil Depth in Inches	2/ Hydrologic Soil Group
(Fk) Fort Collins loam 2 to 4 percent slopes	106	0.48%				
Fort Collins l			95%	101	60" 4/	C
McRae l			3%	3	60" 4/	B/C
Thurlow sicl			2%	2	60" 4/	D
(Fm) Fort Collins loam 4 to 8 percent slopes	155	0.71%				
Fort Collins l			95%	148	60" 4/	C
McRae l			5%	7	60" 4/	B/C
(Ga) Galata silty clay 4 to 8 percent slopes	32	0.15%				
Galata sic			95%	31	8"	D
Rapelje, Kyle, Bone			5%	1	0" 3/	-
(Gd) Gilt Edge silty clay loam 2 to 4 percent slopes	39	0.18%				
Gilt Edge sicl			95%	37	3"	D
Shonkin, Hesper, Keiser, Hydro			5%	2	0-10" 3/	-
(He) Harvey complex undulating	88	0.40%				
Harvey gr-l			45%	40	43"	B
Harvey l			45%	40	43"	B
Stormitt, shale outcrop			10%	8	0-17" 3/	-

Table 17. Hanging Woman Creek study area soil mapping acreages.--continued

Mapping Unit/Components	Mapping Unit Acres	Mapping Unit Percent of Total Area	Component Percent of Mapping Unit	Component Acres	1/ Topsoil Depth in Inches	2/ Hydrologic Soil Group
(HGb) Haverson and Lohmiller soils, channeled	772	3.5%				
Haverson l			Varies - undifferentiated group		60" 4/	B
Haverson sicl					60" 4/	B
Lohmiller sicl					60" 4/	C
(Hk) Heldt silty clay loam 2 to 4 percent slopes	34	0.15%				
Heldt sicl			100%	34	6"	C
(Hlc) Heldt silty clay loam 4 to 8 percent slopes	411	1.9%				
Heldt sicl			95%	390	6"	C
Midway sicl			3%	12	3"	D
Lohmiller sicl			2%	9	60" 4/	C
(Hld) Heldt silty clay loam 8 to 15 percent slopes	58	0.26%				
Heldt sicl			98%	57	6"	C
Lohmiller sicl			2%	1	60" 4/	C
(Hlg) Heldt-Hysham silty clay loams 2 to 4 percent slopes	56	0.26%				
Heldt sicl			75%	42	6"	C
Hysham sicl			25%	14	11"	C

Table 17. Hanging Woman Creek study area soil mapping acreages.--continued

Mapping Unit/Components	Mapping Unit Acres	Mapping Unit Percent of Total Area	Component Percent of Mapping Unit	Component Acres	1/ Topsoil Depth in Inches	2/ Hydrologic Soil Group
(Hna) Hydro loam 0 to 8 percent slopes	636	2.9%				
Hydro l			99%	630	10"	C/D
Allentine sicl			1%	6	2"	D
(Hnd) Hydro silt loam 4 to 8 percent slopes	34	0.15%				
Hydro sicl			98%	33	7"	C/D
Richfield, Beauvais			2%	1	5-60" 4/	-
(Hng) Hydro-Allentine complex 1 to 4 percent slopes	25	0.11%				
Hydro l			70%	18	10"	C/D
Allentine sic			30%	7	0" 3/	D
Bone c			<1%	-	0" 3/	D
(Hnh) Hydro-Allentine complex 4 to 8 percent slopes	271	1.2%				
Hydro l			75%	203	10"	C/D
Allentine cl			25%	68	2"	D
(Ho) Hysham loam 0 to 2 percent slopes	9	0.04%				
Hysham l			75%	7	60" 4/	C
Haverson l			25%	2	60" 4/	B

Table 17. Hanging Woman Creek study area soil mapping acreages.--continued

Mapping Unit/Components	Mapping Unit Acres	Mapping Unit Percent of Total Area	Component Percent of Mapping Unit	Component Acres	1/ Topsoil Depth in Inches	2/ Hydrologic Soil Group
(Ku) Kyle silty clay 4 to 8 percent slopes	46	0.21%				
Kyle sic			99%	45	0" 3/	D
Vanada c			1%	1	0" 3/	D
(Kn) Kyle clay 8 to 15 percent slopes	79	0.36%				
Kyle c			95%	75	0" 3/	D
Vanada, Galata, Rapelje			5%	4	0" 3/	-
(Lr) Lohmiller silty clay loam 4 to 8 percent slopes	10	0.05%				
Lohmiller sicl			100%	10	60" 4/	C
(Mr) McRae loam 1 to 4 percent slopes	145	0.66%				
McRae l			95%	138	60" 4/	B/C
McRae sil			5%	7	60" 4/	B/C
(Ms) McRae loam 4 to 8 percent slopes	175	0.80%				
McRae l			95%	166	60" 4/	B/C
McRae sil			5%	9	60" 4/	B/C

Table 17. Hanging Woman Creek study area soil mapping acreages.--continued

Mapping Unit/Components	Mapping Unit Acres	Mapping Unit Percent of Total Area	Component Percent of Mapping Unit	Component Acres	1/ Topsoil Depth in Inches	2/ Hydrologic Soil Group
(Mu) Midway silty clay loam, undulating	112	0.51%				
Midway sicl			95%	106	3"	D
Renohill sicl			5%	6	4"	D
(MVa) Midway silty clay loam, rolling	281	1.28%				
Midway sicl			95%	267	3"	D
Heldt, Lohmiller, McRae, Thedalund, Nelson			5%	14	3-60" 4/	-
(MVb) Midway silty clay loam, hilly	105	0.48%				
Midway sicl			80%	84	3"	D
Lohmiller sicl			10%	11	60" 4/	C
Shale outcrops			10%	10	0" 3/	-
(Mg) Midway-Elso association 8 to 35 percent slopes	714	3.25%				
Midway cl			60%	428	3"	D
Elso sil			30%	214	20"	C
Thurlow, Cushman, Fort Collins			10%	72	24-60" 4/	-

Table 17. Hanging Woman Creek study area soil mapping acreages.--continued

Mapping Unit/Components	Mapping Unit Acres	Mapping Unit Percent of Total Area	Component Percent of Mapping Unit	Component Acres	1/ Topsoil Depth in Inches	2/ Hydrologic Soil Group
(Mw) Midway and Elso rocky soils 35 to 75 percent slopes	191	0.87%				
Midway R-cl			40%	76	0" 3/	D
Elso R-sil			35%	67	0" 3/	C
Rock outcrop			25%	48	0" 3/	-
(MVe) Midway-Thedalund complex, rolling	2111	9.61%				
Midway sicl			55%	1161	3"	D
Thedalund l			30%	633	24"	B/C
Thurlow sicl			10%	211	60" 4/	D
Heldt sicl			5%	106	6"	C
(MVf) Midway-Thedalund complex, hilly	1111	5.06%				
Midway sicl			60%	667	3"	D
Thedalund l			25%	278	24"	B/C
Shale outcrops			15%	166	0" 3/	-
(MVg) Midway-Thurlow association, rolling	257	1.17%				
Midway sicl			60%	154	3"	D
Thurlow sicl			30%	77	60" 4/	D
Renohill sicl			10%	26	4"	D

Table 17. Hanging Woman Creek study area soil mapping acreages.--continued

Mapping Unit/Components	Mapping Unit Acres	Mapping Unit Percent of Total Area	Component Percent of Mapping Unit	Component Acres	1/ Topsoil Depth in Inches	2/ Hydrologic Soil Group
(Mt) Midway-Thurlow association, 8 to 15 percent slopes	919	4.18%				
Midway cl			55%	505	3"	D
Thurlow sicl			45%	414	60" 4/	D
(Nd) Nelson fine sandy loam, undulating	24	0.01%				
Nelson Fsl			95%	23	29"	B
Alice Fsl			5%	1	41%	B
(Ne) Nelson-Alice fine sandy loams, rolling	255	1.16%				
Nelson Fsl			50%	128	29"	B
Alice Fsl			40%	102	41"	B
Travessilla sl			5%	13	8"	D
Rock outcrop			5%	13	0" 3/	-
(Nf) Nelson-Glenberg sandy loams, undulating	29	0.13%				
Nelson sl			50%	15	39"	B
Glenberg sl			40%	12	5"	A/B
Travessilla sl			10%	3	8"	D
(Pg) Pierre clay, undulating	23	0.10%				
Pierre clay			95%	21	0" 3/	D
Shale outcrops			3%	1	0" 3/	-
Lismas c			2%	1	0" 3/	D

Table 17. Hanging Woman Creek study area soil mapping acreages.--continued

Mapping Unit/Components	Mapping Unit Acres	Mapping Unit Percent of Total Area	Component Percent of Mapping Unit	Component Acres	[1] Topsoil Depth in Inches	[2] Hydrologic Soil Group
(Ph) Pierre clay, rolling	101	0.46%				
Pierre c			95%	96	0" [3]	D
Lismas c			3%	3	0" [3]	D
Kyle c			2%	2	0" [3]	D
(Re) Renohill silty clay loam, undulating	31	0.14%				
Renohill sicl			90%	27	4"	D
Midway sicl			5%	2	3"	D
Thurlow sicl			3%	1	60" [4]	D
Heldt sicl			2%	1	6"	C
(SOc) Shale outcrop-Midway complex steep	385	1.75%				
Shale outcrop			50%	193	0" [3]	-
Midway sicl			50%	192	3"	D
(Tg) Thedalund loam, undulating	18	0.08%				
Thedalund l			99%	17	24"	B/C
Thedalund Fsl			1%	1	24"	B
(Thb) Thedalund-Cushman loams, undulating	515	2.35%				
Thedalund l			60%	309	24"	B/C
Cushman l			40%	206	24"	C

Table 17. Hanging Woman Creek study area soil mapping acreages.--continued

Mapping Unit/Components	Mapping Unit Acres	Mapping Unit Percent of Total Area	Component Percent of Mapping Unit	Component Acres	1/ Topsoil Depth in Inches	2/ Hydrologic Soil Group
(THd) Thedalund-McRae loams, dissected	543	2.47%				
Thedalund l			50%	271	24"	B/C
McRae l			40%	218	60" 4/	B/C
Kim l			10%	54	60" 4/	B/C
(THe) Thedalund-Midway complex, rolling	1032	4.70%				
Thedalund l			55%	567	24"	B/C
Midway sicl			30%	309	3"	D
McRae l			15%	156	60" 4/	B/C
(THg) Thedalund-Rock outcrop complex, hilly	314	1.43%				
Thedalund l			55%	125	24"	B/C
Midway sicl			20%	78	3"	D
Rock Outcrop			15%	63	-	-
McRae l			10%	48	60" 4/	B/C
(THk) Thedalund-Travessilla loams, rolling	6342	29.0%				
Thedalund l			40%	2536	24"	B/C
Travessilla l			25%	1585	8"	D
Cushman l			20%	1269	24"	C
Hydro l			15%	952	10"	C/D

Table 17. Hanging Woman Creek study area soil mapping acreages.--continued

Mapping Unit/Components	Mapping Unit Acres	Mapping Unit Percent of Total Area	Component Percent of Mapping Unit	Component Acres	1/ Topsoil Depth in Inches	2/ Hydrologic Soil Group
(THm) Thedalund-Wibaux complex, rolling	10	0.05%				
Thedalund 1			45%	4	24"	B/C
Wibaux 1			40%	3	9"	D
Travessilla 1			10%	1	8"	D
Spearman 1			3%	1	23"	C
Hydro 1			2%	1	10"	C/D
(Tm) Thurlow silty clay loam, 1 to 4 percent slopes	71	0.32%				
Thurlow sicl			100%	71	60" 4/	D
(Tn) Thurlow silty clay loam, 4 to 8 percent slopes	406	1.85%				
Thurlow sicl			80%	325	60" 4/	D
Heldt sicl			10%	41	6"	C
Midway sicl			10%	40	3"	D
(Tr) Thurlow silty clay loam, 8 to 15 percent slopes	215	0.98%				
Thurlow sicl			95%	204	60" 4/	D
Hesper, Fort Collins, Bew			5%	11	6-60" 4/	-

Table 17. Hanging Woman Creek study area soil mapping acreages.--continued

Mapping Unit/Components	Mapping Unit Acres	Mapping Unit Percent of Total Area	Component Percent of Mapping Unit	Component Acres	1/ Topsoil Depth in Inches	2/ Hydrologic Soil Group
(To) Thurlow-Midway silty clay loams, 4 to 15 percent slopes	1197	5.45%				
Thurlow sicl			50%	598	60" 4/	D
Midway sicl			40%	479	3"	D
Lohmiller sicl			10%	120	60" 4/	C
(TS) Travessilla-Thedalund loams, rolling	208	0.95%				
Travessilla l			40%	84	8"	D
Thedalund l			40%	83	24"	B/C
Rock Outcrop			20%	41	0"	-
TOTAL	21,960 acres	100%				

1/ USDA, SCS, 1978
2/ USDA, SCS, 1972 (Table 17A)
3/ Surface and subsurface layers are not suitable for use as a topsoil material, or no soil exists, as with rock outcrops.
4/ Present surface soil is less than 60", but full 60" or more is suitable as topsoil material.

Table 17A. Hydrologic Classification of Soil Series

Hydrologic soil groups are used in watershed planning to estimate runoff from rainfall. Soil properties are considered that influence the minimum rate of infiltration obtained for a bare soil after prolonged wetting. These properties are: depth of seasonally high water table, intake rate and permeability after prolonged wetting, and depth to very slowly permeable layer. The influence of ground cover is treated independently - not in hydrologic soil groups.

The soils have been classified into four groups, A through D. Statements in parentheses following the definition may be helpful to soil scientists wishing to place soils into hydrologic groups using the soil classification system.

A. (Low runoff potential) Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission. (Includes Psamments except those in Lithic, Aquic, or Aquodic subgroups; soils other than those in group C or D in fragmental, sandy-skeletal, or sandy families; soils in Grossarenic subgroups of Udults and Udalfs; and soils in Arenic subgroups of Udults and Udalfs except those in clayey or fine families.)

B. (Moderately low runoff potential) Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep and deep, moderately well and well-drained soils with moderately fine to moderately coarse textures with moderately slow to moderately rapid permeability. These soils have a moderate rate of water transmission. (Soils other than those in groups A, C, or D.)

C. (Moderately high runoff potential) Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of well-drained and moderately well-drained soils with slowly and very slowly permeable layers (fragipans, hardpans, hard bedrock, and the like) at moderate depth (20 to 40 inches), soils with moderately fine to fine texture (or soils with moderate water tables). (These soils may be somewhat poorly drained.) These soils have a slow rate of water transmission. (Includes soils in Albic or Aquic subgroups; soils in aeric subgroups of Aquents, Aquepts, Aquolls, Aqualfs, and Aquults in loamy families; soils other than those in group D that are in fine, very fine, or clayey families except those with kaolinitic, oxidic, or halloysitic mineralogy; Humods and Orthods; soils with fragipans or petrocalcic horizons; soils in shallow families that have permeable substrata; soils in Lithic subgroups that have rock that is pervious or cracked enough to allow water to penetrate.)

D. (High runoff potential) Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly

impervious material. These soils have a very slow rate of water transmission. (Includes all Vertisols; all Histosols; all Aquods; soils in Aquents, Aquepts, Aquolls, Aqualfs, and Aquults except for Aeric subgroups in loamy families; soils with natric horizons; soils in Lithic subgroups that have impermeable substrata; and soils in shallow families that have impermeable substrata).

Soil Chemistry and Mineralogy

(modified from USGS Open-File Report 78-346)

The purpose of this segment of the study is to provide chemical and mineralogical data on the soil resource within the stripping part of the Hanging Woman Creek study area. These data will contribute to the potential-reclamation evaluation in the event that the area is disturbed by strip mining for the underlying coal deposits.

Soil mapping of the area, as shown in Figure 25, was adapted from detailed mapping of the Big Horn County soil survey (SCS, 1977). Morphological descriptions of the map units within the stripping area are given in Appendix D.

The taxonomy of soils that occur in the area is given to summarize the relationships among the soils (Table 18). Although the soil series are listed individually in Table 18, some occur on the land in close association with other series as complexes (Figure 25). Soil properties that are used to define the taxonomic Great Groups are given in the appendix. The characteristics given are in addition to those properties that define the Suborders, which are the next higher taxonomic category. In general, the soils of the study area are shallow, poorly to moderately developed, neutral to alkaline pH, calcareous, and in some cases sodic. The principal types of parent material are sandstone, shale, and alluvium derived from these materials.

The diversity represented by the numerous mapping units reflects taxonomic definitions that are based largely on morphologic properties. The large number of mapping units were condensed into a more manageable number of groups that should reflect differences in the mineralogy and geochemistry as well as broad differences in morphology; the definitions of these groups are shown in Table 19. Properties apparent from soil mapping data are considered such as, the major clay mineralogy, presence or absence of salt affect, and physiographic position. These condensed map units are shown in Figure 25.

Map Unit No. 1 includes alkali- and sodic-affected soils that occur along the valley sides at foot slopes where saline seeps emerge or precipitates accumulate. Some occurrences are found in upland positions where alkali or sodic conditions occur in the parent material. Map Unit No. 2 includes the terraces, fans, and foot slopes of the upper drainages and side slopes. The predominant clay mineralogy as classed as montmorillonitic and the soils are not sodic-affected. Map Unit No. 3 represents predominantly those shallow, residual soils developed on the upland ridges and divides where the more resistant rock outcrops occur. The soil series tend to occur as complexes and the mineralogy is classed

Explanation of map units in Figure 25.

[Map adapted from Progressive Soil Survey, Big Horn County, by Soil Conservation Service, Hardin, Montana unpub. data); used by permission of SCS]

Explanation

(23) Sample number: 1st digit - soil group; 2nd digit - sample within group.

Map unit	Soil series	Slope (percent)
	Soil Group 1:	
Ayd	Arvada sicl	0-4
Aye	Arvada-Bone	0-4
Gd	Gilt Edge sicl	2-4
Hna	Hydro l	0-8
Hnc	Hydro sil	2-4
Hnh	Hydro-Allentine	4-8
Ho	Hysham l	0-2
Vc	Vananda c	1-8
	Soil Group 2:	
Hlc	Heldt sicl	4-8
Hld	Heldt sicl	8-15
Hlg	Heldt-Hysham	2-4
Mu	Midway sicl	2-8
MVa	Midway sicl	8-15
Tm	Thurlow sicl	1-4
Tn	Thurlow sicl	4-8
To	Thurlow-Midway	4-15
	Soil Group 3:	
CW	Colby-Midway	8-15
Cz	Cushman l	4-8
MVe	Midway-Thedalund	8-15
MVf	Midway-Thedalund	8-35
Ne	Nelson-Alice	8-20
THd	Thedalund-McRae	4-35
THe	Thedalund-Midway	8-15
THk	Thedalund-Travesilla	2-15
THl	Thedalund-Wibaux	4-8
THm	Thedalund-Wibaux	8-15
TS	Travesilla-Thedalund	8-15
	Soil Group 4:	
Fk	Fort Collins l	2-4
Fm	Fort Collins l	4-8
Hfa	Haverson l	0-2
HGb	Haverson-Lohmiller	0-35
Lr	Lohmiller sicl	4-8
Mr	McRae l	1-4
Ms	McRae l	4-8
	Others:	
SOc	Shale outcrop-Midway	20-90
THg	Thedalund-rock outcrop	15-35

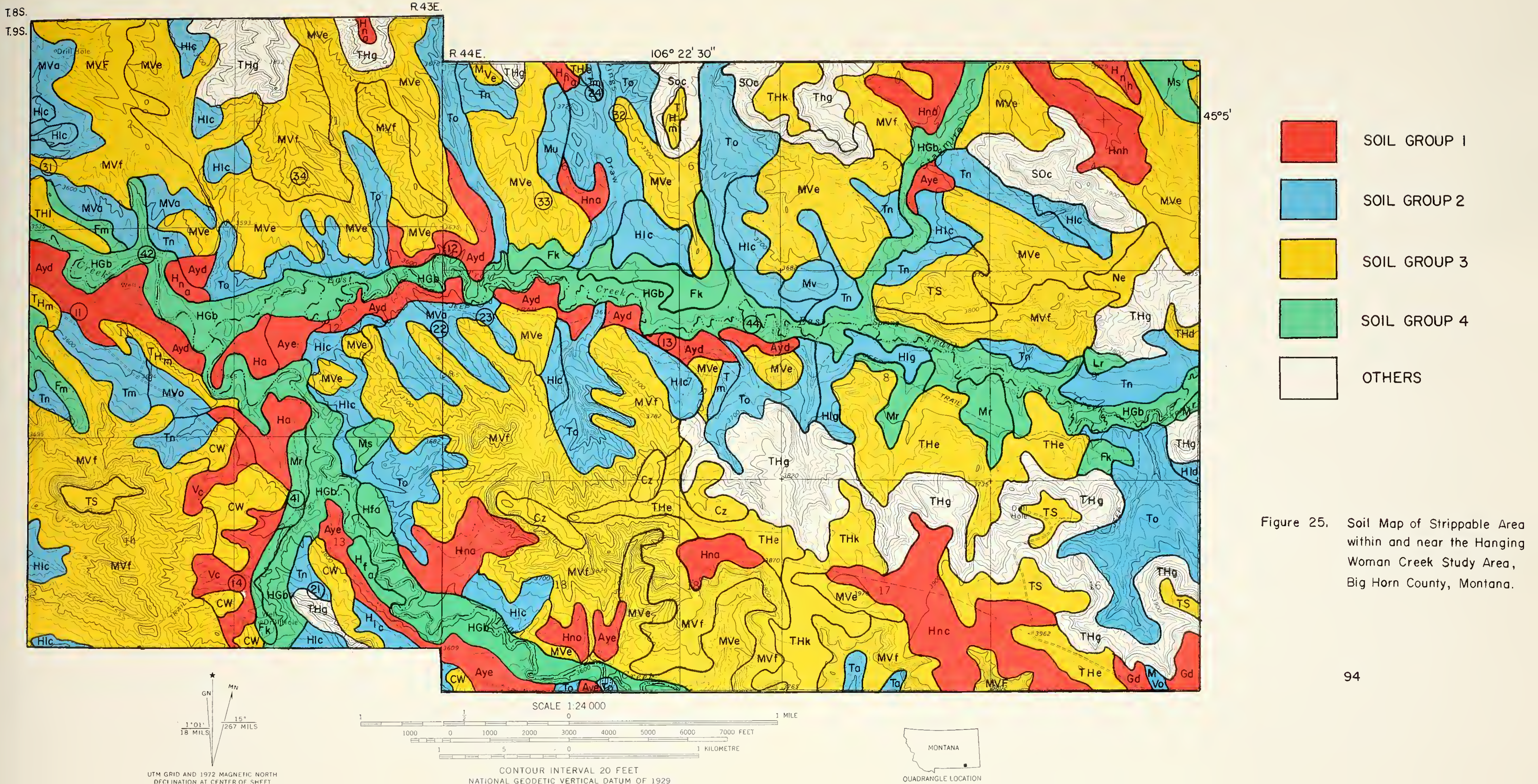


Figure 25. Soil Map of Strippable Area within and near the Hanging Woman Creek Study Area, Big Horn County, Montana.

Table 18.--Classification of soil series occurring in the Hanging Woman Creek study area.

Series	Soil taxonomy		Parent material	Physiog. position	Alkali and salt status
	Subgroup	Family			
Alice	Aridic haplustoll	Coarse-loamy, mixed, mesic	Sandstone colluvium	Footslopes, heads of drainages	Subsoil strongly calcareous
Allentine	Haplustollic natrargid	Fine, montmorillonitic, mesic	Alluvium	Fans, terraces	Pan spot
Arvada	Ustollic natrargid	do.	Mixed clay and loam alluvium	Fans, terraces, floodplains	Alkali-affected, calcareous
Bone	Ustic torriorthent	Fine, montmorillonitic (calcareous), mesic	Alluvium	do.	Pan spot, often barren
Colby	do.	Fine-silty, mixed (calcareous), mesic	Alluvium or aeolian	Terraces well above present valleys, ridges	Subsoil strongly calcareous, lime pockets
Cushman	Ustollic haplargid	Fine-loamy, mixed, mesic	Shale and sandstone	Residual-ridges, hilltops	Subsoil, moderately calcareous
Fort Collins	do.	do.	Deep alluvium	Terraces, fans, footslopes	Subsoil strongly calcareous
Gilt Edge	Haplustollic natrargid	Fine, montmorillonitic, mesic	Clay alluvium	do.	Subsoil strongly calcareous, lime, gypsum, salt
Haverson	Ustic torrifluvent	Fine-loamy, mixed (calcareous) mesic	Alluvium	Terraces, floodplains	Subsoil calcareous
Heldt	Ustertic camorthid	Fine, montmorillonitic, mesic	Silty clay loam alluvium	Terraces, fans, and footslopes	Lime and gypsum in subsoil
Hydro	Glossic ustollic natrarigid	do.	Clay loam and silty clay loam alluvium containing moderate sodium	Terraces, fans, benches along large stream valleys	Subsoil calcareous
Hysham	Ustic torrifluvent	Fine-loamy, mixed (calcareous), mesic	Loamy alluvium	Terraces, fans, footslopes	Sodium-affected, strongly alkaline
Lohmiller	do.	Fine, montmorillonitic (calcareous) mesic	Alluvium	Terraces, floodplains	Subsoil calcareous
McRae	Ustollic camorthid	Fine-loamy, mixed, mesic	Deep alluvium	Fan terraces, footslopes	Subsoil calcareous in pockets and seams
Midway	Ustic torriorthent	Clayey, montmorillonitic (calcareous), mesic, shallow	Silty shales	Divides and ridges	Salt and gypsum interbedded in shale layers
Nelson	do.	Coarse-loamy, mixed (calcareous), mesic	Calcareous sandstone	Residual on sedimentary plains	Subsoil calcareous
Thedalund	do.	Fine-loamy, mixed (calcareous), mesic	Shale	do.	Subsoil calcareous, may have salt and gypsum pockets
Thurlow	Ustollic haplargid	Fine, montmorillonitic, mesic	Deep silty clay loam alluvium	Terraces, fans, footslopes	Subsoil strongly calcareous, segregated lime and gypsum
Travessilla	Lithic ustic torriorthent	Loamy, mixed (calcareous), mesic	Calcareous sandstone	Residual on sedimentary plains	Subsoil calcareous
Vananda	Ustic torriorthent	Fine, montmorillonitic (calcareous), mesic	Deep clay alluvium	Terraces, fans, footslopes	Subsoil alkaline, gypsum, exchangeable sodium percentage greater than 7
Wibaux	do	Loamy-skeletal over fragmental, mixed, nonacid, mesic			

Table 19.--Description of soil groups and soil series sampled in each group.

Soil group no.	Description
1	Montmorillonitic, alkali- or sodic-affected; terraces, fans, and footslopes. Series sampled: 3-Arvada (Ayd), 1-Vananda (Vc).
2	Montmorillonitic, non-sodic affected; terraces, fans, footslopes, ridges. Series sampled: 2-Midway (MVa), 2-Thurlow (Tm).
3	Montmorillonitic and mixed mineralogy; complexes in upland positions. Series sampled: 4-Midway-Thedalund (MVe, MVf).
4	Mixed mineralogy; recent alluvium. Series sampled: 3-Haverson-Lohmiller (HGb), 1-McRae (Mr).

as montmorillonitic and mixed. Map Unit No. 4 includes soils of mixed mineralogy that are developed on alluvium within the main valley bottom.

Sampling Procedures

The chemical and mineralogical variability of the soils was initially unknown. It was, therefore, necessary to obtain representative samples of each of the four combined mapping units. Accordingly, four sampling localities within each of the mapping units were randomly selected for a total of 16 localities. The mapping units that were sampled are given in Table 19; locations are shown in Figure 25. At each locality, two profiles were selected that were separated by a random distance of 3 to 328 feet (1 to 100 m). A channel sample of the A or A-plus-B horizons (if present) of one profile was composited with a similar sample from the other profile. A corresponding composite sample of the C horizons was obtained from depths that had a typical range of about 24 to 32 inches (60 to 80 cm), or less if the depth to bedrock was less.

Laboratory Procedures

All soil samples were thoroughly air dried at ambient temperature and gently disaggregated by a mechanical, ceramic mortar and pestal. Only the material passing a 2-mm stainless steel screen was used for further analysis. A representative subsample was prepared for chemical analysis by grinding to -100 mesh in a ceramic grinder. The methods of analysis used, the elements measured, and the lower limits of determination are given in Table 20. Each sample was scanned for 64 elements by emission spectroscopy with an automatic plate reader. Typically, only about 20-25 elements are found in soils above the limit of determination. Other chemical procedures, such as atomic absorption, neutron activation, and wet-chemical techniques were used for selected elements for which the normal ranges of concentration were below the limits of determination by the spectrographic method. All samples were analyzed in laboratories of the U.S. Geological Survey in Denver, Colorado by the following analysts: emission spectrography, Merlyn W. Solt and Kathryn E. Horan; x-ray fluorescence, James S. Wahlberg, James W. Baker, and Michele L. Tuttle; Li, Mg, Na, and Rb by atomic absorption, Wayne Mountjoy and Carol A. Gent; F by specific-ion electrode, Harriet Nieman and Patricia G. Guest; C by Paul H. Briggs and Van E. Shaw; Cd and Zn by atomic absorption, James G. Crock; Hg by flameless atomic absorption, James A. Thomas; U and Th by neutron activation, Hugh T. Millard, Jr., Caryl L. Shields, C. M. Ellis, R. L. Nelms, and C. A. Ramsey; and pH, George O. Riddle. Particle-size analysis and x-ray diffraction were done by Mike P. Pantea.

A randomly-selected group of 16 samples, 8 each of the A-horizon samples and of the C-horizon samples, were split into duplicates to estimate the magnitude of the analytical error. These duplicates were randomly intermixed among the other samples and the entire suite was analyzed in a random order to transform any systematic errors into random errors.

Table 20.--Methods of analyses and lower limits of determination for elements measured in soil samples.

Method	Elements	Lower limit of determination	Reference
Emission spectroscopy (plate reader)	Common elements		U.S. Geol. Survey (1976, p. 131-132)
	B	-[1/]	
	Ba	-	
	Be	-	
	Co	-	
	Cr	-	
	Cu	-	
	Ga	-	
	La	-	
	Mn	-	
	Nb	-	
	Ni	-	
	Pb	-	
	Sc	-	
	Sr	-	
	V	-	
	Y	-	
	Yb	-	
	Zr	-	
	Rare elements (parts per million)		
	Ce	21	
	Mo	2.1	

Table 20.--Methods of analyses and lower limits of determination for elements measured in soil samples--continued.

Method	Elements	Lower limit of determination	Reference
X-ray fluorescence	Major elements (percent)		Miesch (1976, p. 11-12)
	Al	0.3	
	Ca	.07	
	Fe	.04	
	K	.025	
	Si	.25	
	Ti	.03	
	Minor elements (parts per million)		
	As	.5	
	Ge	.5	
	Sb	.5	
	Se	.5	
	Sn	.5	
Atomic absorption (parts per million)			Miesch (1976, p. 12-14)
	Cd	1	
	Hg	.01	
	Li	5	
	Mg	180	
	Na	75	
	Rb	10	
	Zn	10	
Selective-ion electrode (parts per million)			Do.
	F	40	
	pH	-	2/

Table 20.--Methods of analyses and lower limits of determination for elements measured in soil samples--continued

Method	Elements	Lower limit of determination	Reference
Gasometric (parts per million)			
	Total C	500	Miesch (1976, p. 13)
Neutron activation (parts per million)			
	Th	2	U.S. Geol. Survey (1975, p. 79-81)
	U	.1	

1/ Lower limit of determination is not reported for most elements by emission spectroscopy because it varies due to sample dilution.

2/ pH determined by glass electrode in water-saturated paste. Lower-limit-of-determination value not applicable.

Particle-size analysis and determination of mineralogy were performed on A-horizon samples only. Particle size was determined by a gravimetric separation done in conjunction with preparation for x-ray analysis. Organic matter and carbonate cementing agents were removed by procedures described by Jackson (1975). The mineral assemblage of the sand (2 mm-50 µm), silt (50-2 µm), and clay (less than 2 µm) was determined by x-ray diffraction.

The sand, silt, and clay fractions were each ground to a powder and randomly oriented for x-ray diffraction. Quantitative estimates of the minerals present were made using a computer-assisted analysis of the peak areas. The clay-size fraction was characterized from oriented patterns by treating it with ethylene glycol, and heating to temperatures of 300 and 500° F, respectively, to evaluate expanding clay minerals and kaolinite-chlorite. Also K-saturation and Mg-saturation of the clays was followed by glycerine treatment to distinguish between vermiculite and montmorillonite. Semiquantitative estimates of the abundance of each clay mineral were made by visual inspection of the first-order x-ray diffraction peak area.

Results

The particle-size distributions of the A-horizon samples are shown in Table 21. The textures range from loam to silty clay; however, there is no important textural difference between the soil groups.

The minerals commonly detected in randomly-oriented samples of whole soil and of the sand, silt, and clay fractions include quartz, plagioclase, potassium feldspars, and clay minerals. Calcite and dolomite occur in the whole soil sample but not in the separate size fractions because they were removed by the treatment that was applied. It is noteworthy that gypsum was not detected in the samples. The sources of variation, as determined by analysis of variance, are predominantly associated with either the samples or with laboratory error (Table 22). For most of the minerals, only a minor part of the variance is associated with the soil group level. In other words, there are no significant differences in the mineralogy between the soil groups with the exception of calcite and dolomite. The grand mean, which is estimated from the data, is likely to be a stable estimate but the deviation about that estimate may be rather large.

Mineral amounts, for which there is no significant difference between soil groups, are best estimated by a single grand mean (Table 23). Quartz and the clay minerals are dominant, and the feldspars and carbonates are minor. The percentage of the primary minerals tends to decrease as the particle size becomes smaller; the percentage of the clay minerals is complementary.

Minerals that do exhibit a significant difference between soil groups are best estimated by the individual group means. Calcite is significant at the 0.05 probability level and dolomite is significant at the 0.1 probability level. Group means for these minerals are given in Table 24.

Table 21.--Particle-size analysis of A-horizon samples of soils

[Values in percent]

Sample no.	Sand	Silt	Clay	Soil texture
SOIL GROUP 1				
1	11	52	37	Silty clay loam
2	24	50	26	Loam
3	13	47	40	Silty clay
4	23	49	28	Clay loam
SOIL GROUP 2				
1	16	51	33	Silty clay loam
2	8	53	39	Silty clay loam
3	7	50	43	Silty clay
4	24	45	31	Clay loam
SOIL GROUP 3				
1	29	40	31	Clay loam
2	21	49	30	Do.
3	22	49	29	Do.
4	38	33	29	Do.
SOIL GROUP 4				
1	43	36	21	Loam
2	19	50	31	Silty clay loam
3	35	40	25	Loam
4	29	50	21	Silt loam

Table 22.--Variance components of primary minerals in A-horizon samples of whole soil and separate size fractions.

[Values, percentage of total variance. Asterisk (*), significant at 0.05 probability level]

Mineral	Soil groups	Samples[1/]	Analyses
WHOLE SAMPLE			
Quartz ---------------	35	61	4
Plagioclase ----------	19	49	32
Potassium feldspar ---	0	87	13
Calcite --------------	81*	18	1
Dolomite -------------	48	26	26
Clay -----------------	22	72	6
SAND FRACTION (2 mm - .05 mm)			
Quartz ---------------	0	88	12
Plagioclase ----------	0	57	42
Potassium feldspar ---	0	32	68
Clay -----------------	0	88	12
SILT FRACTION (.05 mm - .002 mm)			
Quartz ---------------	0	0	100
Plagioclase ----------	34	46	20
Potassium feldspar ---	30	38	32
Clay -----------------	4	0	96
CLAY FRACTION (<.002 mm)			
Quartz ---------------	0	28	72
Plagioclase ----------	0	18	82
Potassium feldspar ---	18	36	46
Clay -----------------	0	13	87

1/ No significance test for samples was made.

Table 23.--Summary statistics of primary minerals in whole samples and separate size fractions of A-horizons of soils.

[Values in percent. Randomly oriented X-ray diffraction. Means, no significant differences between soil groups]

Mineral	Grand mean	Standard deviation
WHOLE SAMPLE[1/]		
Quartz--------------	42	7.6
Plagioclase---------	7.6	2.2
Potassium feldspar--	5.4	2.3
Clay minerals-------	40	6.8
SAND FRACTION (2 mm - .05 mm)		
Quartz--------------	74	7.1
Plagioclase---------	8.6	3.0
Potassium feldspar--	9.1	2.1
Clay minerals-------	8.5	4.9
SILT FRACTION (.05 mm - .002 mm)		
Quartz--------------	60	5.8
Plagioclase---------	12	2.0
Potassium feldspar--	7.3	2.0
Clay minerals-------	21	6.2
CLAY FRACTION (<.002 mm)		
Quartz--------------	13	3.9
Plagioclase---------	4.0	3.1
Potassium feldspar--	1.6	2.8
Clay minerals-------	81	6.4

[1/] Total percentage includes calcite and dolomite.

Table 24.--Summary statistics for calcite and dolomite in A-horizon samples of soils.

[Values in percent. Numbers in parentheses, soil group number. Underscore, means without significant differences by Duncan's multiple range test. Data, randomly oriented X-ray diffraction of whole soil samples]

Mineral	Standard deviation	Standard error	Group means			
			(1)	(4)	(2)	(3)
Calcite---	1.71	0.41	0.55	0.58	5.0	8.6
			(1)	(4)	(3)	(2)
Dolomite--	.85	.61	.88	2.1	2.2	2.5

A semiquantitative estimate of the several clay minerals in the clay-size fraction is given in Table 25. The predominant minerals include illite, kaolinite, and interlayered illite-montmorillonite with minor occurrences of montmorillonite-vermiculite, montmorillonite, and chlorite. There are no outstanding differences between the soil groups.

The sources of variation in the chemical data for both A- and C-horizons were determined by analysis of variance (Tables 26 and 27). The data were transformed to logarithms, except as noted, because the frequency distributions are more nearly normal on a log scale. The estimate of analytical-error variance was derived from a separate analysis of variance of the duplicates. Because of this, there is no test of significance for the samples. Significant differences between soil groups were found for 14 elements in the A-horizon. There were 19 elements in the C-horizon that had significant differences between soil groups, 13 of these being the same as in the A-horizon. The following elements were judged to have excessive analytical error: barium, lanthanum, mercury, molybdenum, selenium, and tin in the A-horizon; and beryllium, cerium, lanthanum, lead, molybdenum, selenium, ytterbium, and zirconium in the C-horizon. Therefore, no summaries are given for these elements.

Because there are significant differences between soil groups for some elements, the individual means for each group are the best estimates of average concentration of these elements (Table 28). The analysis of variance indicates a difference only between the largest and the smallest means; any possible differences between other means were tested by Duncan's multiple-range test (Duncan, 1955). Groups of means that are not significantly different are indicated by underscores in Table 28.

Elements for which there is no significant difference between soil groups are best described by a single grand mean, which is shown in Table 29. A 95% expected range is also given: this indicates that an additional sample would have a concentration that would be either above or below the range only one time out of 20 due to chance alone. The expected range is calculated on the basis of an estimate of the natural variation from which the analytical error has been removed.

Discussion

Significant differences between the soil groups were found primarily among the major elements (aluminum, calcium, carbon (carbonate), iron, magnesium, potassium, silicon, and titanium). Because the mapping units were condensed, in part, on the basis of the presence or absence of alkali and/or sodic conditions, it is surprising that we find no significant differences in sodium. There are, however, differences in calcium, magnesium, and carbonate with the soil groups developed on alluvium (including group 1, which is designated as "alkali- or sodic-affected", and group 4) having the lowest concentrations. The largest concentrations of these constituents are associated with residual soils in upland positions where calcite and dolomite are more predominant.

Table 25.--Semiquantitative estimates of clay-mineral abundance in the clay-size fraction (less than .002 mm) of A-horizons of soils.

[A, abundant, greater than 40 percent. I, intermediate, 15-40 percent. M, minor, less than 15 percent]

Sample number	Mont.[1/]	Mont.-illite	Mont.-vermiculite	Illite	Kaolinite	Chlorite
			SOIL GROUP 1			
1			A	I	I	M
2		I		I	A	I
3		I		I	I	M
4		I	I	I	A	
			SOIL GROUP 2			
1		I		I	I	M
2		I		I	I	M
3		I		I	M	I
4		A		I	M	
			SOIL GROUP 3			
1		A		I	I	M
2			A	I	I	
3	A		M	I	I	M
4		I		I	I	M
			SOIL GROUP 4			
1		I		M	I	
2		I		I	I	M
3				I	I	M
4		M		I	I	

1/ Montmorillonite

Table 26.--Variance components for elements and pH in A-horizon soil samples.

[Values, percentage of total logarithmic variance except as noted. Asterisk (*), significant at 0.05 probability level. Analytical error estimated separately from partial duplicate analyses]

Elements	Variance components, percent		
	Soil groups	Samples	Analyses
Al[1/]	59*	37	4
As	2	80	18
B	32	37	31
Ba	28	0	72
Be	28	45	27
C, carbonate	51*	47	2
C, organic	2	90	8
Ca	76*	24	<1
Ce	19	21	60
Co	32	45	23
Cr	47*	39	14
Cu	2	35	63
F	3	82	15
Fe[1/]	65*	33	2
Ga	18	44	38
Ge	29	25	46
Hg	23	0	77
K	84*	12	4
La	0	37	63
Li	74*	22	4
Mg[1/]	44*	56	<1
Mn	44*	12	44
Mo	5	6	89
Na[1/]	5	90	5
Nb	28	17	55
Ni	50*	37	13
Pb	1	51	48
Rb	87*	0	13
Sc	20	48	32
Se	0	32	68
Si[1/]	54*	41	5
Sn	0	0	100
Sr	34	51	15
Th	22	44	34
Ti[1/]	46*	35	19
U	11	80	9
V	35	40	25
Y	14	39	47
Yb	0	58	42
Zn	58*	39	3
Zr	24	22	54
pH	26	47	27

[1/] Variance estimated from nonlog data.

Table 17.--Variance components for elements and pH in C-horizon soil samples.

[Values, percentage of total logarithmic variance except as noted. Asterisk (*), significant at 0.05 probability level. Analytical error estimated separately from partial duplicate analyses]

Elements	Variance components, percent		
	Soil groups	Samples	Analyses
Al[1/] ----------	42*	40	18
As ----------	0	87	13
B -----------	13	36	51
Ba ----------	31	18	51
Be ----------	25	0	75
C, carbonate -	48*	49	3
C, organic ---	<1	96	4
Ca ----------	63*	37	<1
Ce ----------	22	0	78
Co ----------	52*	3	45
Cr ----------	57*	25	18
Cu ----------	39*	24	37
F -----------	32	63	5
Fe[1/] ----------	60*	35	5
Ga ----------	56*	0	44
Ge ----------	40*	22	38
Hg ----------	0	55	45
K -----------	40*	54	6
La ----------	0	0	100
Li ----------	37	61	2
Mg[1/] ----------	52*	48	>1
Mn ----------	51*	35	14
Mo ----------	0	0	100
Na[1/] ----------	0	99	1
Nb ----------	34	0	66
Ni ----------	62*	12	26
Pb ----------	16	0	84
Rb ----------	30	43	27
Sc ----------	54*	3	43
Se ----------	28	0	72
Si[1/] ----------	63*	35	2
Sn ----------	0	61	39
Sr ----------	70*	0	30
Th ----------	0	62	38
Ti[1/] ----------	58*	40	2
U -----------	12	80	8
V -----------	46*	22	32
Y -----------	0	26	74
Yb ----------	0	0	100
Zn ----------	53*	47	<1
Zr ----------	0	0	100
pH ----------	0	27	73

[1/] Variance estimated from nonlog data.

Table 28.--Summary statistics of element concentrations in soils samples that have significant differences between soil groups.

[Values, parts per million except as noted percent. Number in parentheses, soil-group identifier (see figure 1). Means ranked in ascending order. Underscore, class of means by Duncan's multiple-range test, no significant difference between means within the class. Statistics based on logarithmic data, except as noted nonlog]

Elements	Soil horizon	Geometric deviation	Geometric error	Geometric means of soil groups			
Al, percent[1/]	A	0.17	0.018	(4) 4.8	(3) 5.2	(2) 5.7	(1) 6.0
	C	.31	.099	(4) 4.2	(3) 4.8	(1) 5.2	(2) 5.5
C, carbonate, percent	A	2.83	1.23	(1) .08	(4) .33	(2) .82	(3) 1.3
	C	1.54	1.11	(4) .49	(1) .76	(2) 1.3	(3) 1.3
Ca, percent	A	1.48	1.05	(1) .93	(4) 1.5	(2) 3.1	(3) 4.6
	C	1.30	1.02	(4) 1.8	(1) 2.9	(2) 3.7	(3) 4.3
Co	C	1.27	1.26	(4) 6.7	(1) 8.5	(3) 10	(2) 13
Cr	A	1.22	1.11	(4) 46	(3) 66	(1) 69	(2) 75
	C	1.30	1.19	(4) 36	(1) 55	(3) 69	(2) 76
Cu	C	1.59	1.44	(4) 18	(1) 35	(3) 38	(2) 50
Fe, percent[1/]	A	.076	.0049	(4) 2.0	(1) 2.6	(3) 2.7	(2) 3.0
	C	.18	.022	(4) 1.8	(1) 2.4	(3) 2.6	(2) 3.1
Ga	C	1.31	1.38	(4) 8.3	(1) 11	(3) 14	(2) 18
Ge	C	1.20	1.16	(3) 1.1	(2) 1.4	(4) 1.4	(1) 1.6
K, percent	A	1.05	1.02	(3) 1.5	(2) 1.8	(4) 1.8	(1) 2.0
	C	1.07	1.02	(3) 1.5	(4) 1.7	(1) 1.7	(2) 1.8
Li	A	1.08	1.03	(3) 21	(4) 23	(1) 28	(2) 28
Mg, percent[1/]	A	.049	.0002	(4) .86	(1) .89	(2) 1.3	(3) 1.3
	C	.12	.0004	(4) .77	(1) 1.1	(3) 1.5	(2) 1.6
Mn	A	1.26	1.23	(4) 400	(3) 490	(1) 500	(2) 710
	C	1.38	1.19	(4) 360	(1) 420	(3) 560	(2) 830
Ni	A	1.26	1.13	(4) 22	(3) 32	(1) 34	(2) 41
	C	1.31	1.25	(4) 19	(1) 26	(3) 34	(2) 44
Rb	A	1.06	1.09	(3) 64	(2) 79	(4) 83	(1) 95
Sc	C	1.37	1.36	(4) 6.0	(1) 7.6	(3) 12	(2) 14
Si, percent[1/]	A	2.57	.26	(3) 27	(2) 27	(1) 30	(4) 31
	C	4.49	.25	(2) 26	(3) 26	(1) 29	(4) 32
Sr	C	1.18	1.18	(4) 170	(1) 240	(3) 290	(2) 300
Ti, percent[1/]	A	.001	.0003	(4) .26	(3) .28	(2) .32	(1) .32
	C	.001	.0001	(4) .23	(1) .28	(3) .31	(2) .32
V	C	1.26	1.20	(4) 57	(1) 77	(3) 86	(2) 100
Zn	A	1.10	1.03	(4) 73	(3) 78	(1) 91	(2) 93
	C	1.17	1.02	(4) 60	(1) 78	(3) 79	(2) 93

Table 29.--Summary statistics of element concentrations and pH in soil samples that do not have significant differences between soil groups.

[Values, parts per million except as noted percent. Statistics estimated from 16 samples, logarithmic data except as noted nonlog]

Element	Soil horizon	Geometric mean	Geometric deviation	Geometric error	Expected 95% range
As -----------	A	7.6	1.38	1.13	4.2-14
	C	7.3	1.47	1.15	3.6-15
B ------------	A	43	1.17	1.03	32-59
	C	41	1.28	1.20	29-57
Ba -----------	C	480	1.16	1.12	400-580
Be -----------	A	1.9	1.41	1.19	1.1-3.4
C, organic, percent -----	A	1.2	1.33	1.09	.70-2.1
	C	.59	2.41	1.19	.11-3.3
Ce -----------	A	56	1.57	1.36	29-110
Co -----------	A	9.7	1.41	1.18	5.3-18
Cu -----------	A	36	1.44	1.34	23-56
F, percent ----	A	.055	1.19	1.07	.04-.08
	C	.058	1.26	1.06	.037-.091
Ga -----------	A	13	1.45	1.26	7.3-23
Ge -----------	A	13	1.27	1.18	9.2-18
Hg -----------	C	.03	1.46	1.25	.02-.05
Li -----------	C	24	1.24	1.03	16-37
Na, percent[1/] --	A	.72	.19	.040	.35-1.1
	C	.77	.22	.026	.33-1.2
Nb -----------	A	8.4	1.56	1.39	4.6-15
Pb -----------	A	7.7	1.55	1.36	4.1-14
Rb -----------	C	73	1.21	1.10	52-100
Sc -----------	A	10	1.42	1.23	5.7-18
Sn -----------	C	1.2	1.22	1.13	.88-1.6
Sr -----------	A	210	1.25	1.09	140-320
Th -----------	A	9.9	1.15	1.09	7.9-12
	C	9.9	1.16	1.09	7.8-13
U ------------	A	3.0	1.13	1.04	2.4-3.8
	C	3.4	1.21	1.06	2.4-4.9
V ------------	A	87	1.27	1.13	58-130
Y ------------	A	24	1.19	1.13	19-31
	C	23	1.29	1.24	18-30
Yb -----------	A	3.2	1.26	1.16	2.2-4.6
Zr -----------	A	300	1.29	1.21	210-420
pH[1/] -----------	A	8.1	.34	.21	7.6-8.6
	C	8.4	.40	.34	8.0-8.8

[1/] Nonlog data, arithmetic mean, standard deviation, and standard error given.

In general, most of the other elements including chromium, cobalt, copper, gallium, manganese, nickel, scandium, strontium, titanium, vanadium, and zinc also have the highest concentrations in the residual soil materials. Other elements such as germanium, lithium, potassium, rubidium, and silicon tend to be more concentrated in the alluvial soils of group 1.

The sodium values of all soil groups are not at all unusual when compared with numerous other soils developed on the Fort Union Formation in other parts of the region. The apparent failure to confirm a salinity condition that was predicted from the taxonomic designation reflects the level of mapping intensity. More detailed information is needed for localities of interest. Reliable indicators that can be used include the presence of halophytic vegetation, the occurrence of barren pan spots, or the measurement of conductivity soil extracts.

For those elements that exhibit significant differences at the group level, more than 40% of the total variance measured in the element has been accounted for. The variance may reflect factors such as the original mineralogy and the course of weathering processes that are incorporated in the group concept. The differences between soil groups were similar regardless of what soil horizon was sampled, except that a few more elements were significant in the C-horizon. This suggests at least two alternate conditions: if two unstratified soil profiles both had chemically similar A-horizons, then it is probable that the C-horizons will also be similar. Alternatively, two profiles that are chemically stratified because of either different mineral material or differential leaching of soluble constituents may have chemically similar A-horizons but chemically dissimilar C-horizons.

There are no important differences between the soil groups in terms of the primary minerals with the exception of calcite and dolomite. Calcite occurs in larger amounts in the upland positions where soils are often shallow and the parent material has a dominant influence. Differences for dolomite are less distinct than for calcite but larger amounts are associated with upland positions.

The predominant clay minerals occur in about equal proportions of interlayered montmorillonite-illite, separate illite, and kaolinite with minor amounts of chlorite and vermiculite. The influence of these mineral types on the engineering properties of the soils increases in the order kaolinite<illite<montmorillonite (Mitchell, 1976). Chlorite is approximately in the range of kaolinite-illite and vermiculite is approximately equal to illite-montmorillonite. The engineering behavior is largely a function of the swelling and shrinking of the clay minerals upon wetting and drying.

Moisture Relations in Soils

Moisture regimens in soils, which function as reservoirs for water used by native vegetation, are a product of the semi-arid climate characteristic of the Hanging Woman Creek study area. Approximately one-fourth of the moisture arrives as snow during the period when vegetation is dormant (USDA, 1941). Snow is subject to redistribution by winds; hence, the quantity that falls on a site is not necessarily available for infiltration and storage when the snow melts. Moisture stored in soils as a result of snowmelt is supplemented by water derived from spring and early summer rains. Peak storage probably occurs near the end of the snowmelt period. Maximum runoff from the surface probably occurs under conditions where an intense rainstorm occurs coincident with periods of maximum moisture storage in soils.

Void space and quantity of surface available to store water are the two factors that control moisture relations in soils. These two factors are, therefore, the basis for the concepts, analyses, and interpretations presented in this section. A complete discussion of the concepts used has been presented by Miller and McQueen (1978).

Soils associated with plant communities, occupying the various habitats occurring naturally in the area, were sampled in September 1976. Locations of the sampling sites are shown on Figure 26. All the measurements required to define moisture relations were obtained as products of the method of McQueen and Miller (1968) for measuring the force with which moisture is retained. The data resulting from these measurements are listed in Appendix H. The retention force is determined from the moisture content of standard filter papers at equilibrium with moisture in samples augered from consecutive depth increments in soil profiles. All the soil obtained from each auger increment is retained so that the volume weight (VW), or weight per unit volume, which is the same as bulk density, can be determined. Amounts of void space influence infiltration and storage of water. Void moisture capacity (VMC) is a measure of the quantity of water contained when all of the voids in the soil are filled. Void-moisture capacity values, in percent of dry weight, are computed, assuming that soil particles have a density of 2.65 g/cm^3 and that the density of water is 1 g/cm^3. The equation used is:

$$VMC = \left(\frac{1}{VW} - \frac{1}{2.65}\right)$$

This relationship is presented graphically in Figure 27. The influence of differences in amounts of adsorptive surface in soils on quantities of water that can be retained, over the moisture range from saturation to ovendry, were determined using the modeling technique proposed by McQueen and Miller (1974). The soil, for which a graphic model is presented in Figure 28, has one-half the adsorptive surface per unit of weight adsorbed as multimolecular films to external surfaces of soil particles, are consistently one-half the quantities adsorbed to surfaces of fibers in the paper.

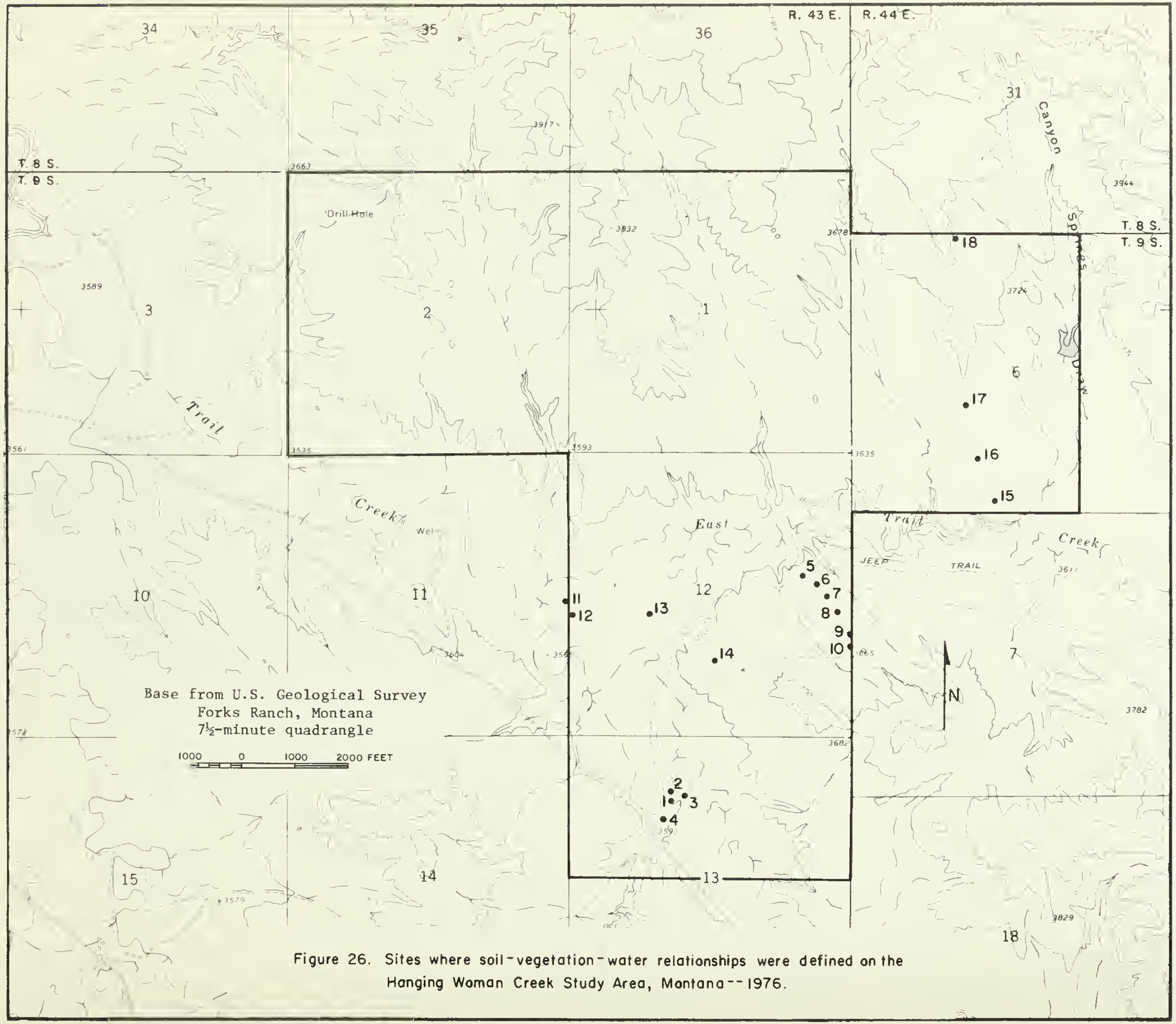


Figure 26. Sites where soil-vegetation-water relationships were defined on the Hanging Woman Creek Study Area, Montana--1976.

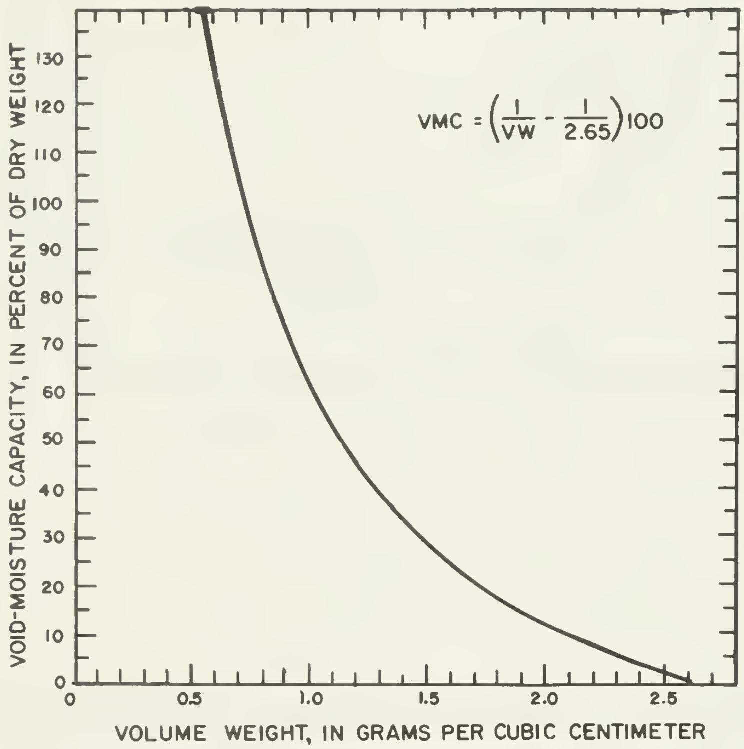


Figure 27. Relationship Used to Determine Void-Moisture Capacity (VMC) of Soils from Volume Weight (VW).

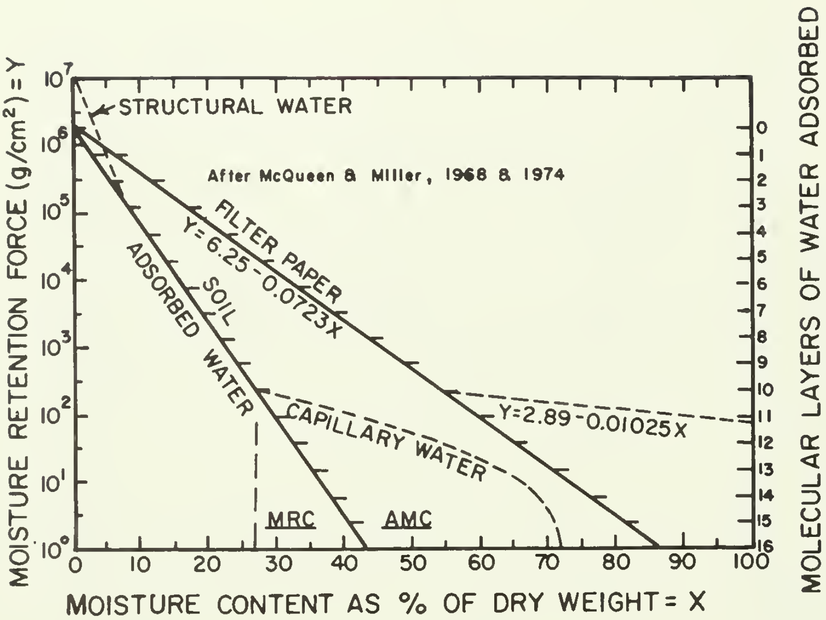


Figure 28. Calibration Relationships (McQueen and Miller, 1968) for Determining Moisture-Retention Force from Moisture Content of Standard Filter Papers at Equilibrium with Moisture in Samples of Soil, and Graph Illustrating Similar Relations in a Soil with One-Half the Adsorptive Surface.

A similar graphic model of moisture content-retention force relationships can be created for any sample of soil if moisture content and retention-force data are acquired under conditions where only adsorbed water is present. The line representing quantities of water adsorbed is extended down from $10^{6.25}$ g/cm^2 on the vertical axis through a point representing the moisture content of the soil and the retention force determined from the filter paper at equilibrium with the soil. Soils that contain expanding latice clays, unlike the filter paper, can adsorb water within their structure. There is evidence (Miller and McQueen, 1972) that this occurs under conditions where retention forces exceed 10^5 g/cm^2.

Water adsorbed as multimolecular films tends to drain down from the adsorption-moisture capacity (AMC) level where 16 molecular layers are adsorbed and the retention force is 10^0 or 1 g/cm^2. Drainage continues to the moisture-retention capability (MRC) level where 10 molecular layers remain adsorbed and the retention force is 222 or $10^{2.346}$ g/cm^2. The retention force increases from 1 to 2.46 and gradually to 6.05, 36.6, and finally to 222 g/cm^2 as drainage slows proportionately. The final large increase results in drainage becoming insignificant at the MRC level where the retention force is $10^{2.346}$ or 222 g/cm^2. During this process, the retention force increases 2.46 times as each molecular layer of water is desorbed. The logarithm of 2.46 is 0.391; therefore, the exponent of the retention force increases by 0.391 as each molecular layer is desorbed.

Molecular dimensions of void spaces in a given depth increment of soil can be used to approximate infiltration rates. The average size of voids available for infiltration and storage of water can be approximated in terms of molecular dimensions of water. This is done by dividing VMC values by MRC values and multiplying by 10, because 10 molecular layers are adsorbed at the MRC level. Infiltration data at sites where a large rainfall-simulating infiltrometer (Lusby and Toy, 1976) was used were made available by Lusby (unpublished data, 1976) for comparison with void-dimension data. The data plot has a linear relationship (Figure 29) that permits estimation of rates of infiltration within confidence limits of plus or minus 9 mm/hr. Since void size and adsorptive surface are controlling factors, the relationship is applicable anywhere.

Quantities of water that can be present in soils between the limits provided by VMC and minimum levels of storage (MS) are divided into adsorbed and drainable portions as shown in Figures 30 through 36. Adsorbed moisture (AMC) is computed as the difference between MRC and MS values. Drainable moisture is computed as the difference between VMC and MRC values. Both are computed to the depth where drainable moisture is capable of occurring. Moisture contents initially computed as percent of the dry weight of soil are converted to numbers indicating depths of adsorbed or drainable water. This is done by multiplying percent moisture by the average VW of the depth increment involved. The product of this multiplication is then multiplied by the depth of the soil increment. The result is the amount of water expressed as a depth of water in millimeters (mm).

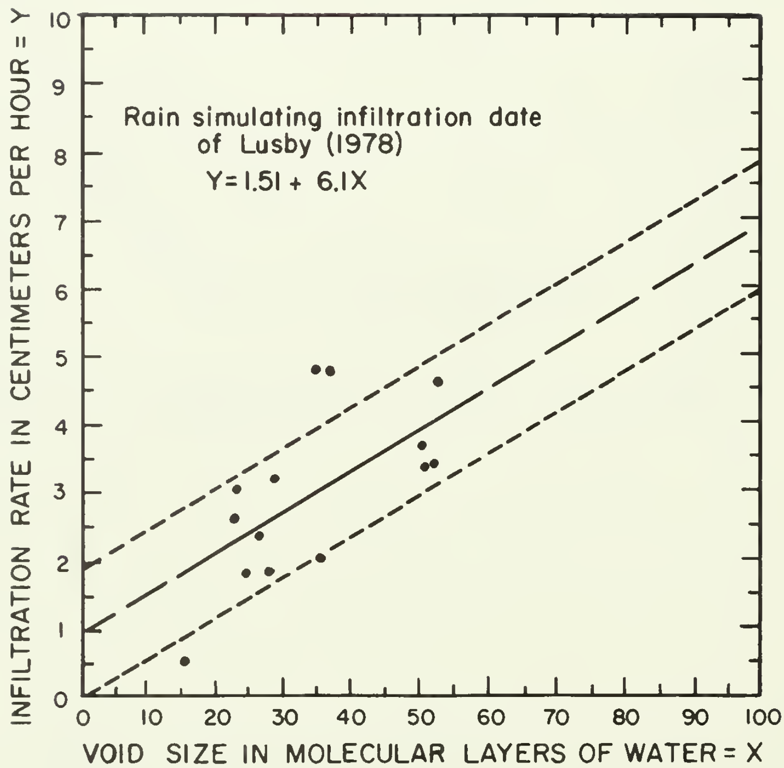


Figure 29. Relationships between Size of Voids and Rate at which Water Infiltrates into Soils. Dashed Line Represents Confidence Limits Based on the Standard Error of Estimate Obtained for the Data.

Study Sites

Habitats ranging from flood plains to hilltops were sampled in the Hanging Woman Creek study area. Sites are grouped for discussion on the basis of gross similarities in geomorphic position so that soil variables influencing use of water by vegetation could be determined. This information should be useful for determining if factors essential to reproducing the habitat can be reestablished when soil materials are repositioned after coal has been removed. Consideration should also be given to determining if more productive habitats can be created by reconstructing soils in a different manner.

Proportions of different kinds of vegetation, mulch, and bare soil occurring naturally in each habitat were determined from the first contact made with a pin along a transect 100 paces long.

Flood Plains

Shrubs with roots that imbibe ground water and subsequently exude it into soil near the surface where it can be used by grasses occur in frequently flooded areas (Table 30). Such a mechanism was proposed as a result of an investigation of the moisture relations of shrubs growing on a low river terrace in Arizona (McQueen and Miller, 1972). Shallow-rooted grasses and solar radiation remove the water from the upper soil zone to where the adsorbtive and osmotic stresses become greater in the soil than the forces on the waters in the roots. Then, water moves from the roots into the dry soil, thus making additional water available to the grasses beyond moisture that enters the soil at the surface.

Table 30.--Kinds and proportions of cover and average retention force at sampling time for flood plain sites.

Cover (percent)	Site H-1	Site H-11
Bare soil		5
Mulch	2	13
Forbs	3	1
Western wheatgrass	57	38
Silver sagebrush	38	2
Greasewood		27
Saltgrass		14
Retention force (g/cm^2)	186	513

Water tables were encountered at a depth of 9.8 ft (3 m) at both sites in Figure 30. Water retained at forces lower than the MRC was present above the water table at both sites. This occurred to the theoretical capillary limit of 7.2 ft (2.2 m) above the water table at Site H-1 where the soil exhibited intermediate to low MRC's at all depths. It occurred to a height of only 5.2 ft (1.6 m) at Site H-11 where the soil had intermediate to high MRC's. Moisture was also depleted to lower levels of storage and to greater depths in the finer-textured alluvium (Site H-11, Figure 30).

Wetting from the surface is impeded by a layer of very fine soil present below the 1.7 ft (0.5 m) depth at Site H-11. This has resulted in voids that limit the moisture content to less than MRC levels. The retention force, where nine molecular layers are present, is sufficient to prevent drainage to greater depths. As a result, vegetation must use more water from the capillary fringe and more of the total water stored in the surface soil. The higher level of sorption force required to obtain the necessary water (Figure 30, Table 30) has resulted in a difference in plant cover. Western wheatgrass and silver sagebrush dominate the site with good drainage (H-1) while greasewood and saltgrass, as well as western wheatgrass, predominate at the site with impeded drainage.

The presence of fresh sediment at the surfaces of both sites results in poor structure. This is reflected by the relatively small amount of void space. Infiltration, as computed by the relationship in Figure 29, is limited to approximately 32 in/hr (8 mm/hr). Prolonged flooding would be required to saturate available voids at both sites; although, total runoff would occur sooner at Site H-1.

If sites such as these are mined, they will not be suitable for reestablishment of shrub vegetation until ground water levels recover. Grassy vegetation, however, could be established similar to that present in swales having deep soils and no ground water.

Alluvial Terraces with Silver Sagebrush

Alluvial terraces with a cover of silver sagebrush or big sagebrush, midgrasses, and short grasses (Table 31) have low to medium MRC's. Site H-2 is Haverson loam; Site H-4 occurs on McRae loam; while Site H-15 occurs on Fort Collins loam. The soils are presented in order of increasing MRC (Figure 31). Silver sagebrush apparently obtains some moisture from the capillary zone above the water tables at these sites. Ground water is closer to the surface in the Fort Collins loam (Site H-15). As a result, the average level of retention force achieved in the process of obtaining water for plant growth is less (Table 31). Proximity of ground water to the surface of the Fort Collins soil (Site H-15, Figure 31) has resulted in less depletion of moisture stored in lower portions of the solum than is evident in the McRae soils (Sites H-2 and H-4, Figure 31).

Initial rates of infiltration into these soils (Figure 31) as approximated from Figure 29 are 1.3, 1.7, and 1.1 in/hr (3.5, 4,4, and

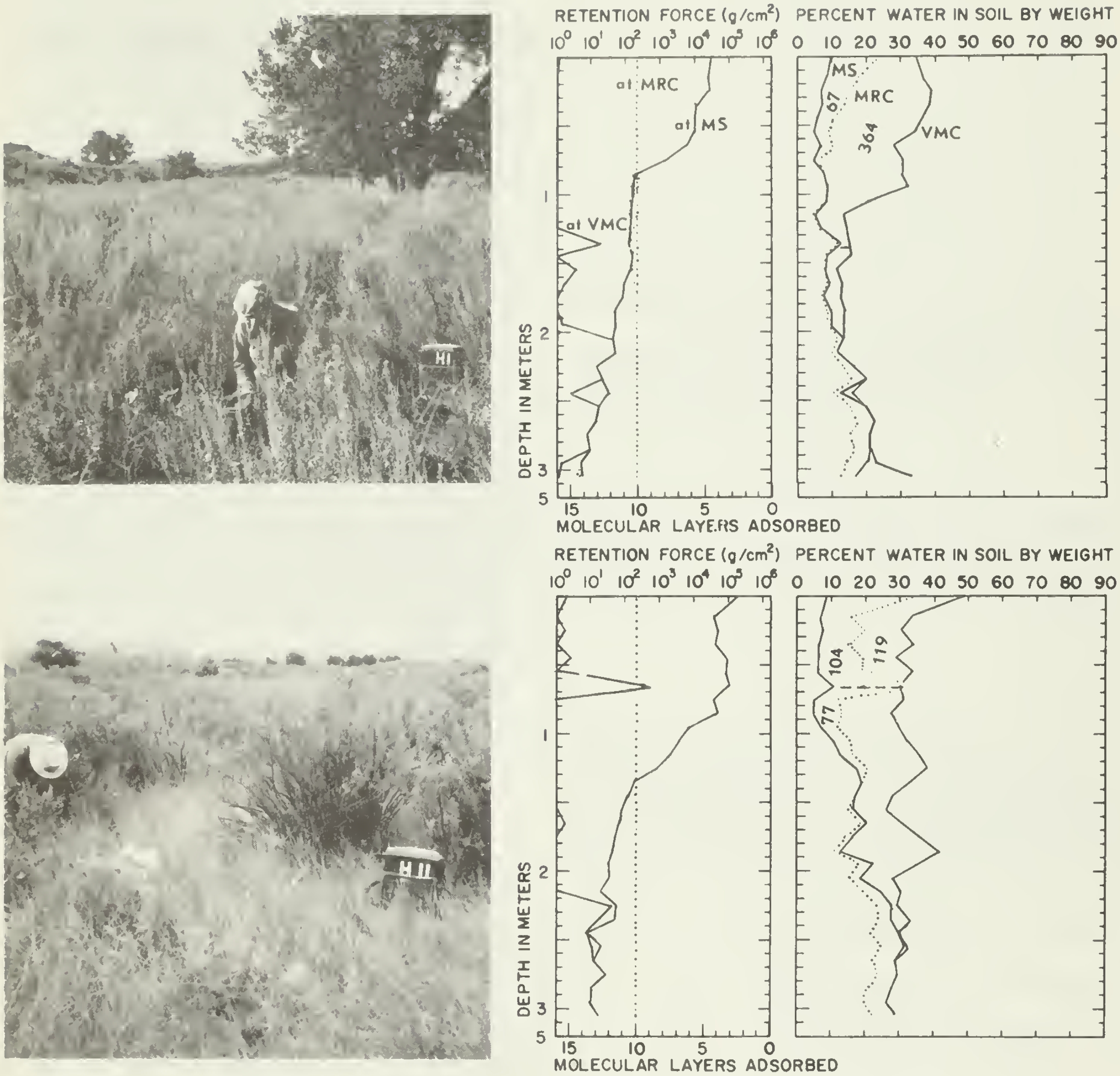


Figure 30.--Moisture relations in habitats occurring on flood plains.

2.9 cm/hr) for Sites H-2, H-4, and H-15, respectively. Drainage is impeded at some depth in all three soils by voids smaller than AMC levels. The restrictions are at 2.7 ft (0.85 m) in soil H-2, and at 9.8 in (0.25 m) in soils H-4 and H-15 (see Figure 31). The head required to cause drainage past these depths is equivalent in centimeters to the retention force in g/cm^2 associated with the number of molecular layers adsorbed. Average permeability to the impeding depths computed from average void capacities and using Figure 29 are 1.0, 1.1, and 0.8 in/hr (2.6, 2.8, and 2.1 cm/hr). It would, therefore, require a minimum of approximately 12 hours to recharge the soil zone above 2.7 ft (0.85 m) at Site H-2 from MS to VMC levels. It would require only 4.5 and 6.7 hours to recharge the upper 9.8 in (0.25 m) of soil at Sites H-4 and H-15. The lesser amounts of water stored above the impeding depth at Sites H-4 and H-15 result in smaller proportions of plant cover than at Site H-2 as indicated by the bare soil data in Table 31.

Table 31.--Kinds and proportions of cover and average retention force at sampling time for alluvial terrace sites with silver sagebrush present.

Cover (percent)	Site H-2	Site H-4	Site H-15
Bare soil	15	19	33
Mulch	6	16	18
Forbs	9		
Silver sagebrush	18	4	14
Big sagebrush		14	4
Fringed sagebrush			3
Western wheatgrass	22	12	18
Needle-and-thread grass	23		
Sandberg bluegrass			8
Cheatgrass	2	1	
Blue grama grass	4	34	
Prickly pear cactus	1		1
Retention force (g/cm^2)	25,119	27,542	3,631

After the soil moisture is recharged above the impeding layer, the infiltration rate at the soil surface is controlled by the rate of flow

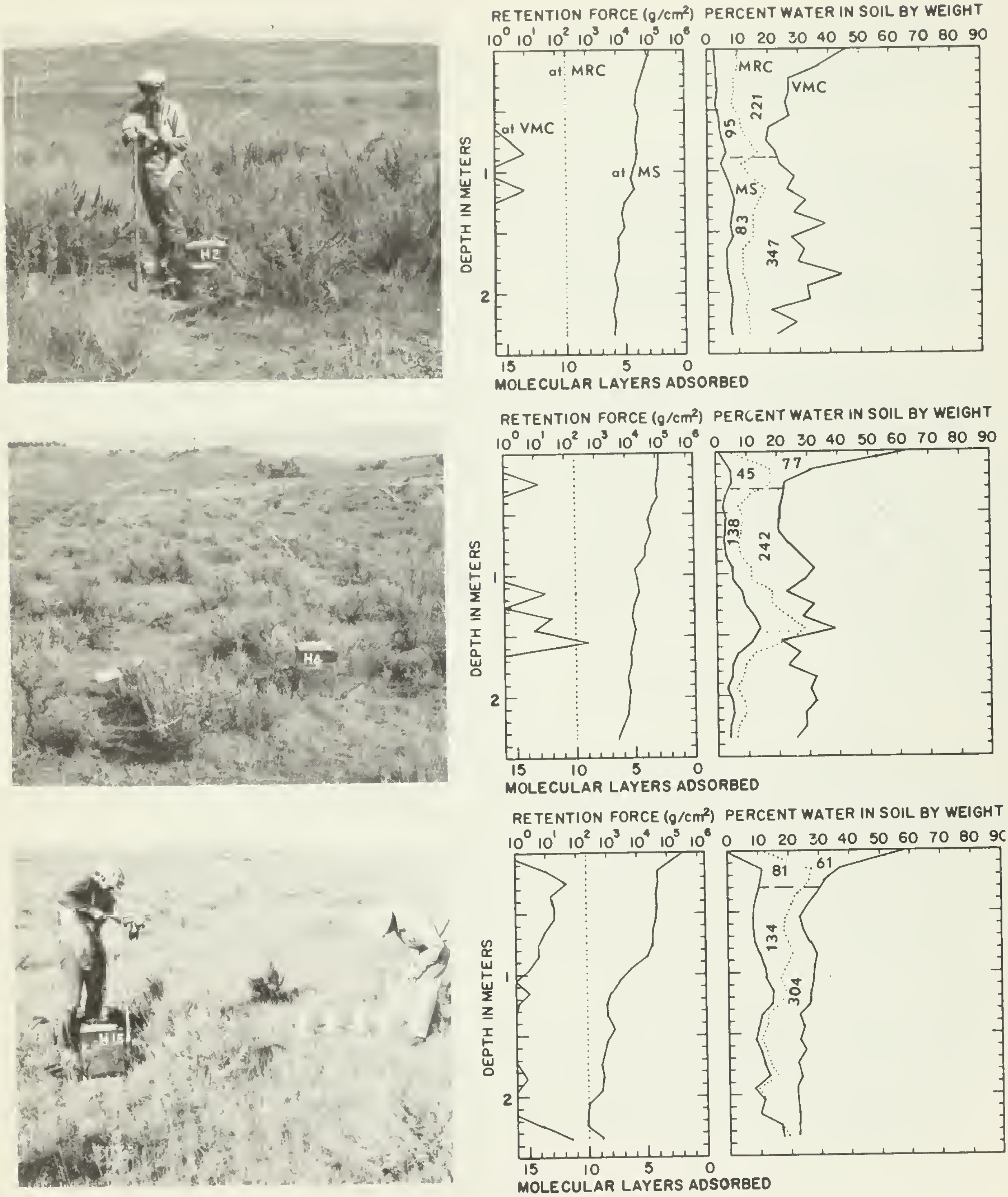


Figure 31.--Moisture relations in soils on alluvial terraces with silver sagebrush present.

past the impeding layer. Because of this, more runoff could occur from prolonged storms than would be indicated by infiltration rates measured at or computed for the soil surface.

Quantities of water that can be stored in surface soils are seemingly responsible for differences in kinds of grasses occurring with shrubs using ground water. Needle-and-thread grass occurs with western wheatgrass at Site H-2 because up to 12.44 in (316 mm) of water can readily enter the soil as compared to only 4.8 and 5.6 in (122 and 142 mm) at Sites H-4 and H-15. The smaller quantities of stored water result in the predominance of blue grama grass at Site H-4 while western wheatgrass predominates at Site H-15 where water is more readily derived from a shallower water table.

Assuming saturation of horizons above the restricting zone, retention force per millimeter of water desorbed can be computed. Any water in excess of retention capability levels will drain to greater depths past the restricting zone, so the average retention force achieved in the solum is divided by quantities of water involved. This procedure indicates that 79 g/cm^2 of force are required to obtain water under midgrasses as compared to 225 g/cm^2 under blue grama, a short grass. The possibility of water from the capillary fringe being available to western wheatgrass in the Fort Collins soil invalidates a similar comparison. Energy required per unit of water desorbed, therefore, appears to influence the kind of vegetation present.

Alluvial Terraces with Greasewood Present

Greasewood occurs with grasses (Table 32) on alluvial terraces where the MRC of the soil varies from intermediate to high (Figure 32). Site H-5 is Greeley silty clay loam; Site H-3 is in Lohmiller silty clay loam; and Site H-12 occurs in an Arvada-Bone clay complex. Sodium derived from decomposing leaves of greasewood (Fireman and Hayward, 1952) has apparently induced poor soil structure at the surface of these soils. Void-moisture capacities (VMC's) at the surface only slightly exceeds MRC levels. As a result, infiltration will be impaired after storage up to MRC levels has been replenished. Void capacities (VMC's) indicate that wetting will probably occur at a rate not to exceed .5 in/hr (1.5 cm/hr). Since infiltration is limited, water is apparently also being supplied to vegetation from ground water. The trend toward lower retention forces with depth in the solum confirms this possibility. Lower portions of the solum are not within 7.2 ft (2.2 m) of the water table, so a mechanism other than capillary rise is responsible for supplying the water. It is probably exuded from the roots of greasewood, which penetrate to the water table, when the water passes in the roots through drier soil near the surface. Void space in excess of MRC levels is still present below the surface soil. These voids are apparently relics of the past when soils at the surface had better structure.

Table 32.--Kinds and proportions of cover and average soil moisture retention force for the profile at time of sampling at sites on alluvial terraces with greasewood present.

Cover (percent)	Site H-5	Site H-3	Site H-12
Bare soil	27	30	30
Mulch	2	10	4
Greasewood	12	10	4
Western wheatgrass	30	30	28
Blue grama grass	10	12	21
Sandberg bluegrass	3	1	
Japanese bromegrass	10		4
Big sagebrush	3		4
Fringed sagebrush	2		
Prickly pear cactus	1	3	4
Cheatgrass		1	
Forbs		3	
Saltgrass			1
Retention force (g/cm^2)	16,982	8,128	4,570

Since only the surface soil has been influenced by sodium from greasewood, it should be removed and not replaced on the surface. Consideration could be given to using fine-textured soils associated with greasewood as subsoils and placing coarse to medium-textured alluvium associated with silver sagebrush as surface soils. This would result in an optimum habitat for native grasses.

Grass-Covered Swales

Grass is the predominant cover in areas mapped as Arvada silty clay loam (Sites H-13 and H-16, Figure 33). These areas lie upslope from areas where greasewood occurs. These grasslands have apparently received alluvium from upslope as they occur in wide swales that drain uplands. Shallow ground water apparently is not present within these grassland soils (Table 33).

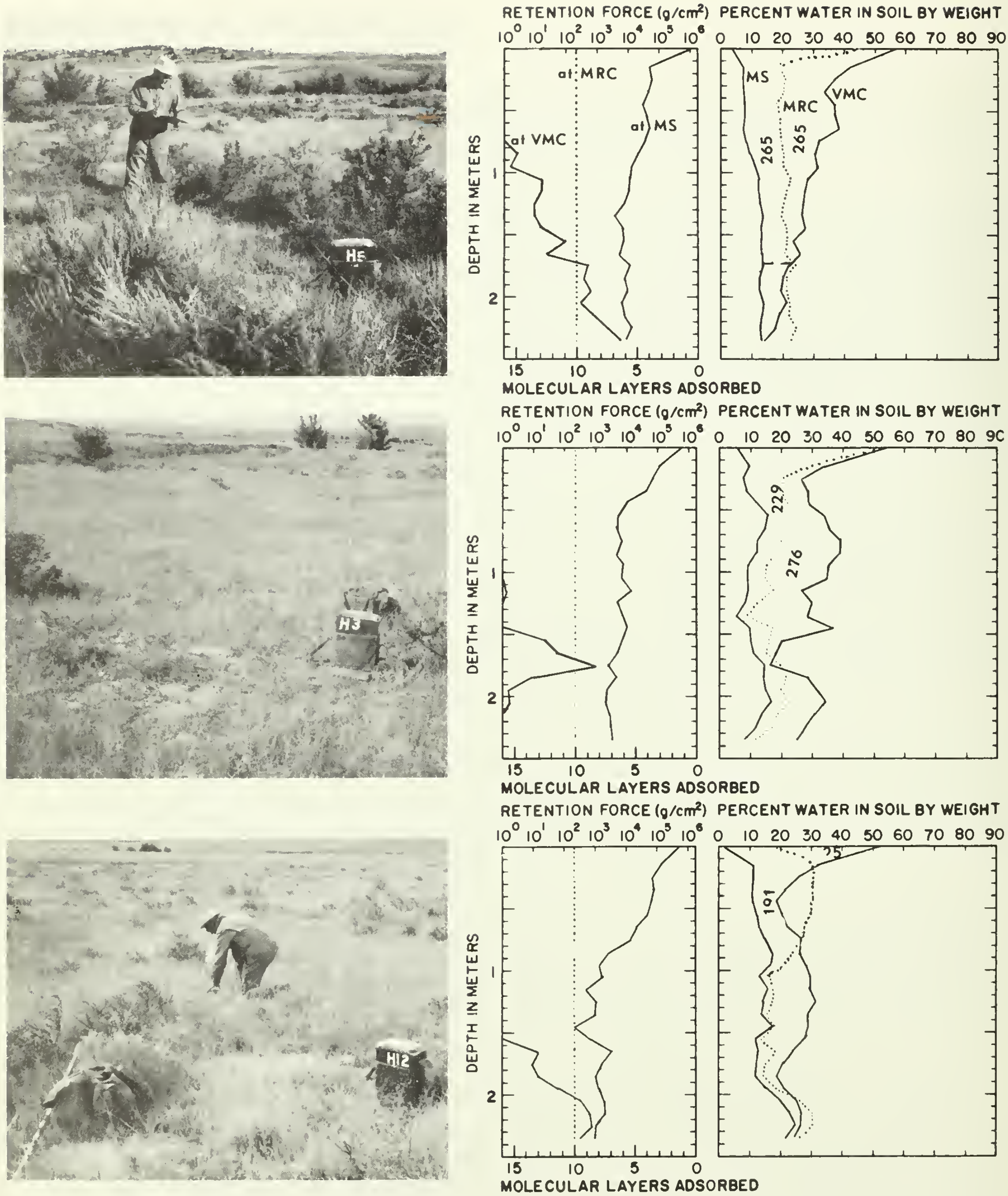


Figure 32--Moisture relations in soils on alluvial terraces where greasewood is present.

Table 33.--Kinds and proportions of cover and average soil moisture retention force in the solum at time of sampling for sites in grass-covered swales.

Cover (percent)	Site H-13	Site H-16
Bare soil	11	12
Mulch	9	6
Western wheatgrass	33	16
Japanese bromegrass	16	42
Green needlegrass		17
Blue grama grass	12	4
Winterfat	13	
Prickly pear cactus	5	3
Forbs	1	
Retention force (g/cm^2)	33,884	33,113

Void-moisture capacities (VMC's) approach MRC levels at relatively shallow depths in both soils, so infiltration rates determined using Figure 29 will soon slow to about .04 in/hr (1.5 cm/hr) as the soil is being wetted. Levels of moisture depletion resulting from evaporation and transpiration are grossly similar in both profiles (Figure 33). Moisture storage at the end of the growth period ranges from six molecular layers at the base of the solum to three molecular layers near the surface. At the immediate surface evaporation has depleted storage to the level where only two molecular layers remain adsorbed. Storage was not at a minimum in these soils because evaporation can deplete moisture to the level where one molecular layer remains adsorbed and the dominant vegetation can deplete moisture to the level where three molecular layers remain adsorbed (Miller and McQueen, 1978). This means that there were moisture reserves present in the soil at the end of the growth period. Some of these reserves will, no doubt, migrate to the surface as vapor when surface soils become cooler than subsoils. These soils are quite similar to the soils with a cover of greasewood in terms of moisture-retention characteristics. The plant cover they support should be indicative of the productive potential of greasewood areas if soil structure can be improved by eliminating salts and sodium extracted from ground water by greasewood. These low areas probably receive extra snow blown off adjacent uplands. If this water can be retained on the

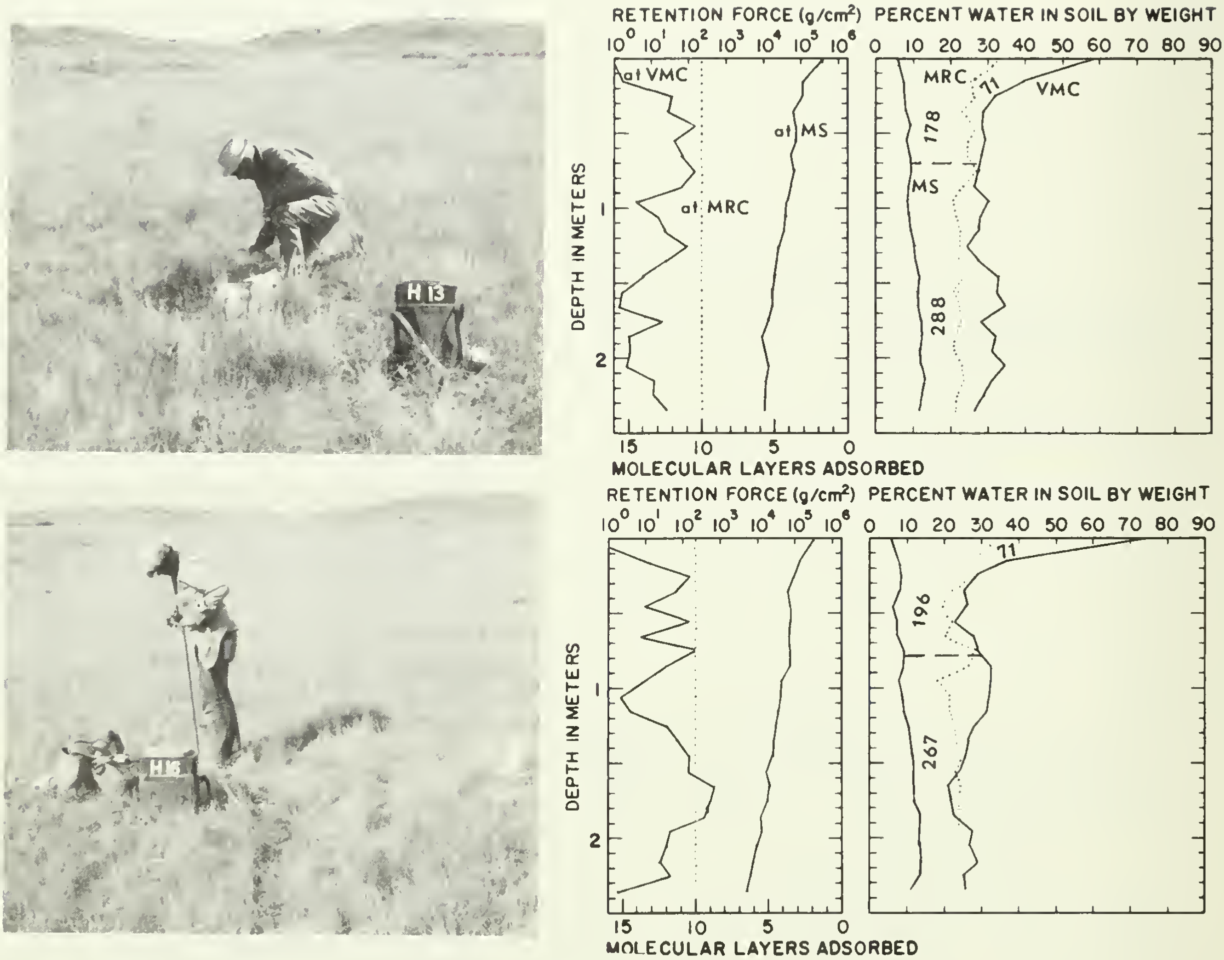


Figure 33.--Moisture relations in soils occurring in swales with a cover of grasses.

surface by tall vegetation or in furrows, adequate structure should result. Leaching of salts including sodium occurs under these conditions (Branson, Miller, and McQueen, 1962).

Gently Sloping Uplands

Midgrasses and shortgrasses with scattered big sagebrush predominate the cover on gently sloping uplands (Table 34, Figure 34). The three sites were all sampled in areas occupied by the Midway or Thedalund soils. Depth to bedrock decreased with distance upslope, so the data are presented to illustrate differences with distance upslope. The major influence of depth to bedrock is on void characteristics. In the deepest soil (Site H-6), voids diminish to MRC levels at a depth of 11.8 in (0.3 m) while voids exceed MRC levels at all depths in the more shallow soils (Sites H-7 and H-17). Water apparently replenishes soils to MRC levels in the deeper soil, but when migration to greater depths is impeded by bedrock, water accumulates separating the soil particles. This results in creation of larger void spaces. The size of voids becomes restricted to less than AMC levels where 16 molecular layers are adsorbed in the surface horizon on all three soils, but voids are less restricted in the shallower soils where perching of water forces soil particles apart. Voids at greatest depths probably fill as a result of water accumulating from rains draining to depth over layers of water previously acquired from snowmelt. Infiltration past the restricting depths is possible at rates of .05, .06, and .07 in/hr (1.4, 1.7, and 1.8 cm/hr) while average rates of infiltration in the surface horizon would be .07, .07, and 1.0 in/hr (1.8, 1.8, and 2.6 cm/hr). At maximum rates of infiltration, it would, therefore, require approximately 7.0, 6.5 and 3.6 hours to saturate the surface horizons of these soils to the point where runoff would occur. The capacity to store moisture in excess of MRC levels is apparently utilized because the average maximum retention force achieved in the solum is less in soils with large void storage capabilities (Table 34).

Sagebrush eradication and replacement with grass is a range management practice that would normally be considered on sites of this type (Shown and others, 1969). Because of this, it should not be considered essential to reestablish sagebrush. A cover of grass would result in more efficient use of the limited soil-water resources available in the area.

Table 34.--Kinds and proportions of cover and average moisture retention force in the solum at the time of sampling on gently sloping uplands.

Cover (percent)	Site H-6	Site H-7	Site H-17
Bare soil	23	40	20
Mulch	6	4	4
Western wheatgrass	10	19	33
Green needlegrass	7		2
Hairy chess grass	5		
Blue grama grass	7	15	10
Sandberg bluegrass	12	2	1
Big sagebrush	13	13	15
Winterfat	7		4
Fringed sagebrush	10	2	4
Snakeweed		5	
Prickly pear cactus			7
Retention force (g/cm^2)	45,709	23,988	12,529

Breaks

Weathered parent rock lies close to the surface on the tops and sides of ridges that divide drainage areas. The sites presented in Figure 35 occur in close proximity to each other in an area mapped as a mixture of Midway-Thedalund soils. The plant cover on these sites is quite variable (Table 35). Broom snakeweed and big sagebrush are the only species common to all sites. Areas of this character are often referred to as "breaks".

Voids in the upper one-half of these soils will readily drain but drainage is restricted in the weathered bedrock beneath where VMC is less than MRC levels (see Figure 35). The capacities of the drainable voids are rather small (1.9, .9, and 3.9 in (50, 22, and 99 mm) of water). The voids at Site H-9 where greasewood occurs appear to have become more restricted below 7.8 in (0.2 m) than they may have been in the past. This

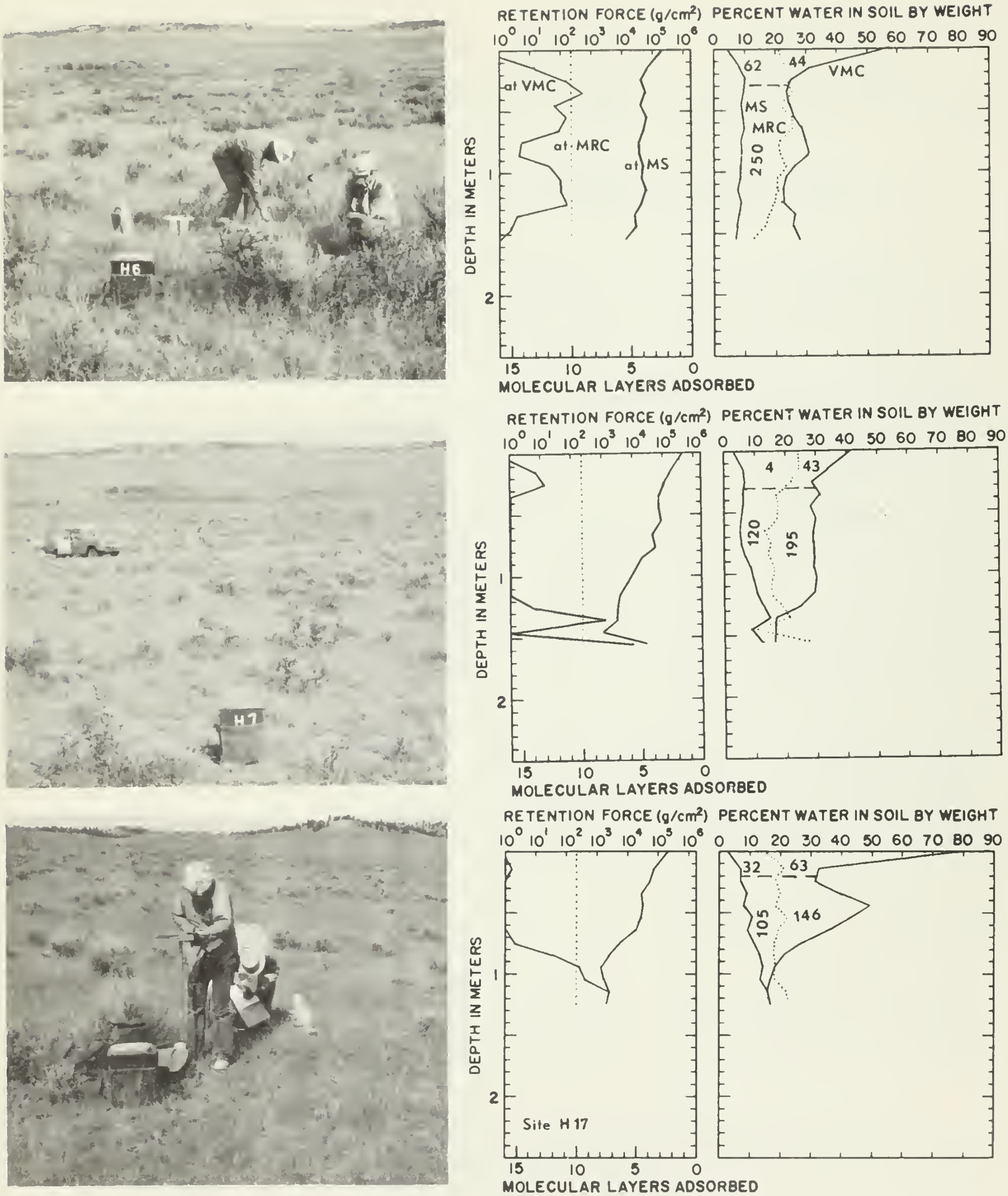


Figure 34.--Moisture relationships in soils on gently sloping uplands.

is probably the result of sodium from greasewood leaves defloculating the soil (Fireman and Hayward, 1952). The other two sites have voids that diminish gradually with depth into less weathered material.

Table 35.--Kinds and proportions of cover and average retention force in the solum at the time of sampling in the breaks.

Cover (percent)	Site H-10	Site H-9	Site H-8
Bare soil	38	42	39
Mulch		4	7
Broom snakeweed	9	1	12
Big sagebrush	6	15	10
Hoods phlox	5		
Mountain muhly	29		
Sandberg bluegrass	10	20	
Blue grama grass	3		
Greasewood		10	
Western wheatgrass		8	
Wild buckwheat		2	
Bluebunch wheatgrass			31
Green needlegrass			1
Retention force (g/cm^2)	6,606	8,709	4,406

Moisture-retention forces achieved at the end of the growth period are rather low in all of these soils (Table 35). An explanation for this may be that available voids are filled with water during wet periods making portions of the stored water available to plants with the expenditure of very little energy. Runoff from these areas will occur when available voids are filled. Average infiltration rates are .8, .6, .8 in/hr (2.1, 1.6, and 2.2 cm/hr) for Sites H-10, H-9 and H-8, respectively, so 100% of the precipitation would runoff within 5.0, 4.6, and 6.9 hours if water is applied at the average rate. If water precipitates at rates that exceed the infiltration capability of soils, air entrapment could induce almost complete runoff. Because of the low ratio of infiltration and small

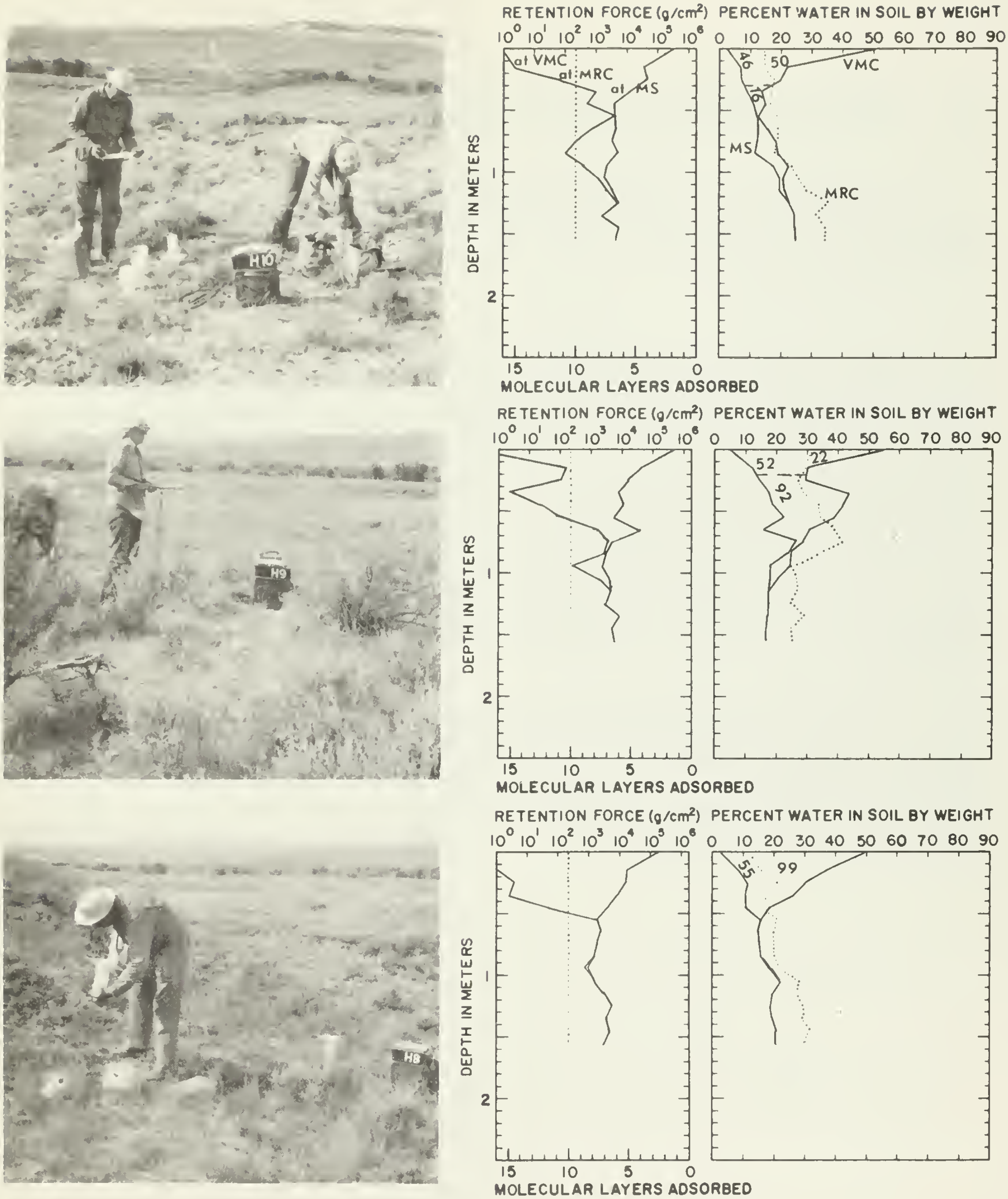


Figure 35.--Moisture relationships in soils in breaks areas.

drainable VMC's, complete runoff is more likely to occur in these areas than in deeper soils that predominate the area. Also, much of the snow that falls probably blows off these ridges.

No real benefit could be derived from attempting to reconstruct these soils after mining. These areas could benefit from gentler slopes and deeper soils. Soil material from deep alluvial deposits could be used for these purposes.

Foot Slopes

Soils immediately downslope from breaks areas (Figure 36) benefit from runoff and sediment accumulation and no doubt from snow accumulation. The availability of extra water is reflected in the presence of drainable voids to greater depths than in the breaks areas. Tall and midgrasses predominate (Table 36) in these areas where water can be perched in voids at retention forces less than the force at MRC level. Site H-14, where there is very little void space for drainage to greater depths at higher retention forces, has the most cover and the lowest average retention force of the two sites. Water apparently drains to greater depths into voids smaller than those at the MRC at Site H-18. This resulted in a higher level of retention force when water was removed from the soil by vegetation.

The comparison between these two sites illustrates how replacing soil materials in a manner that results in perching of water as adsorbed films in excess of the number adsorbed at the retention-capability levels could result in increased productivity per unit of water stored in the soil. Care would be required to insure that there are sufficient voids to hold the water normally available.

Table 36.--Kinds and proportions of cover and average retention force in the solum at time of sampling on foot slopes.

Cover (percent)	Site H-14	Site H-18
Bare soil	19	25
Mulch	3	7
Little bluestem	54	3
Bluebunch wheatgrass	22	6
Prairie sandreed grass		6
Red threeown grass		3
Side oats grama grass		4
Mountain muhly		5
Ponderosa pine		8
Juniper		3
Yucca		5
Prickly pear cactus		5
Rubber rabbitbrush		4
Big sagebrush		4
Silver sagebrush		4
Forbs	2	8
Retention force (g/cm^2)	4,365	15,488

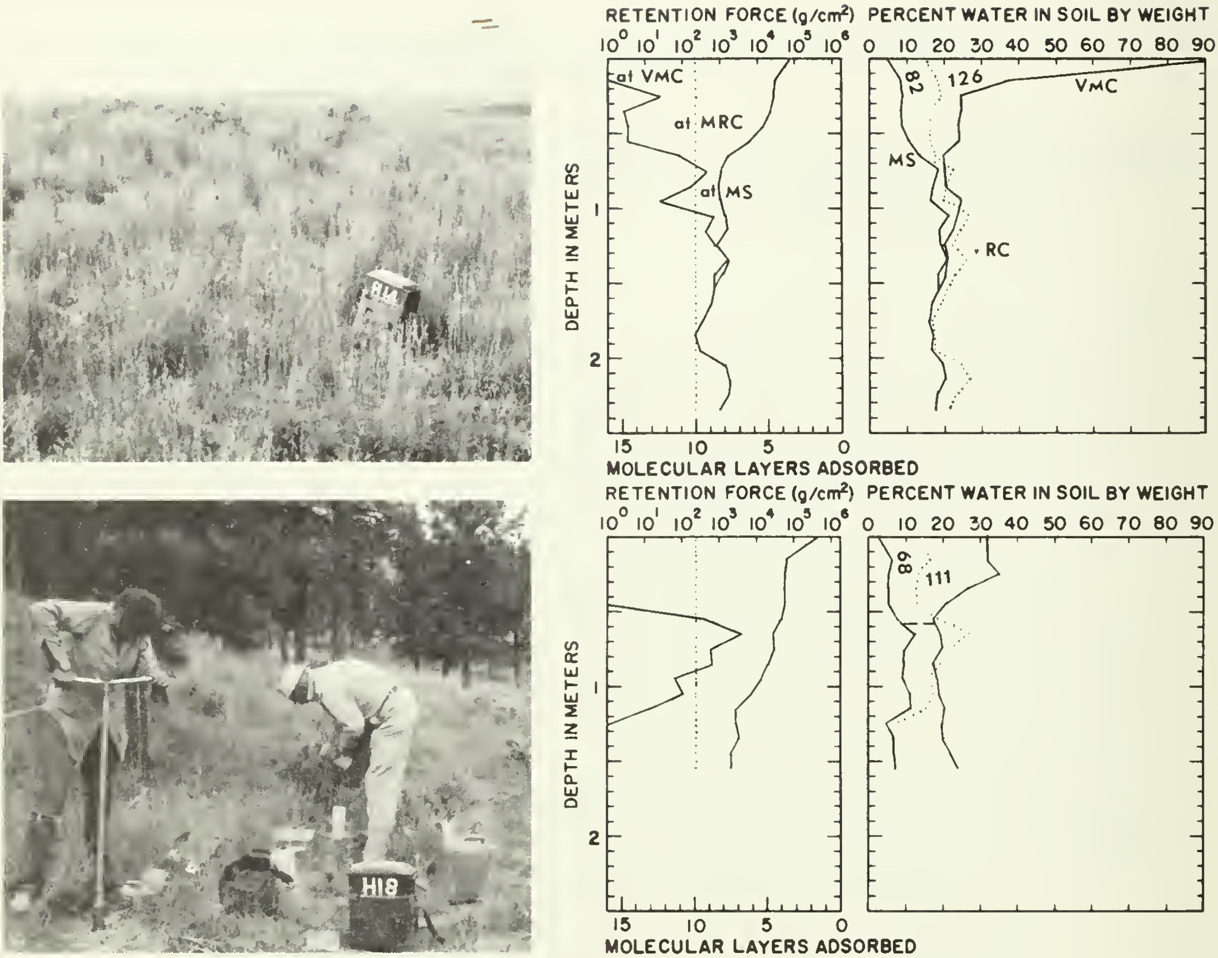


Figure 36.--Moisture relations in soils occurring on foot slopes below breaks areas.

HYDROLOGY

A basic understanding of the hydrology of the Hanging Woman Creek study area is necessary to assess potential effects of mining on local water resources and to suggest alternative solutions to water problems that may occur. This report describes the data collection, hydrologic testing, and data analysis after 1 year of study. The report is the first phase of a continuing study to determine baseline hydrologic conditions and to establish a water-information monitoring network in the study area.

The water-resources investigation described in this report encompasses part of the Hanging Woman Creek coal deposit and the Moorhead coal field along East Trail Creek (Figure 1). Data collection is most extensive near the lower third of the East Trail Creek drainage. Streamflow and water-quality data have been collected at the gaging station East Trail Creek near Otter since November 1976.

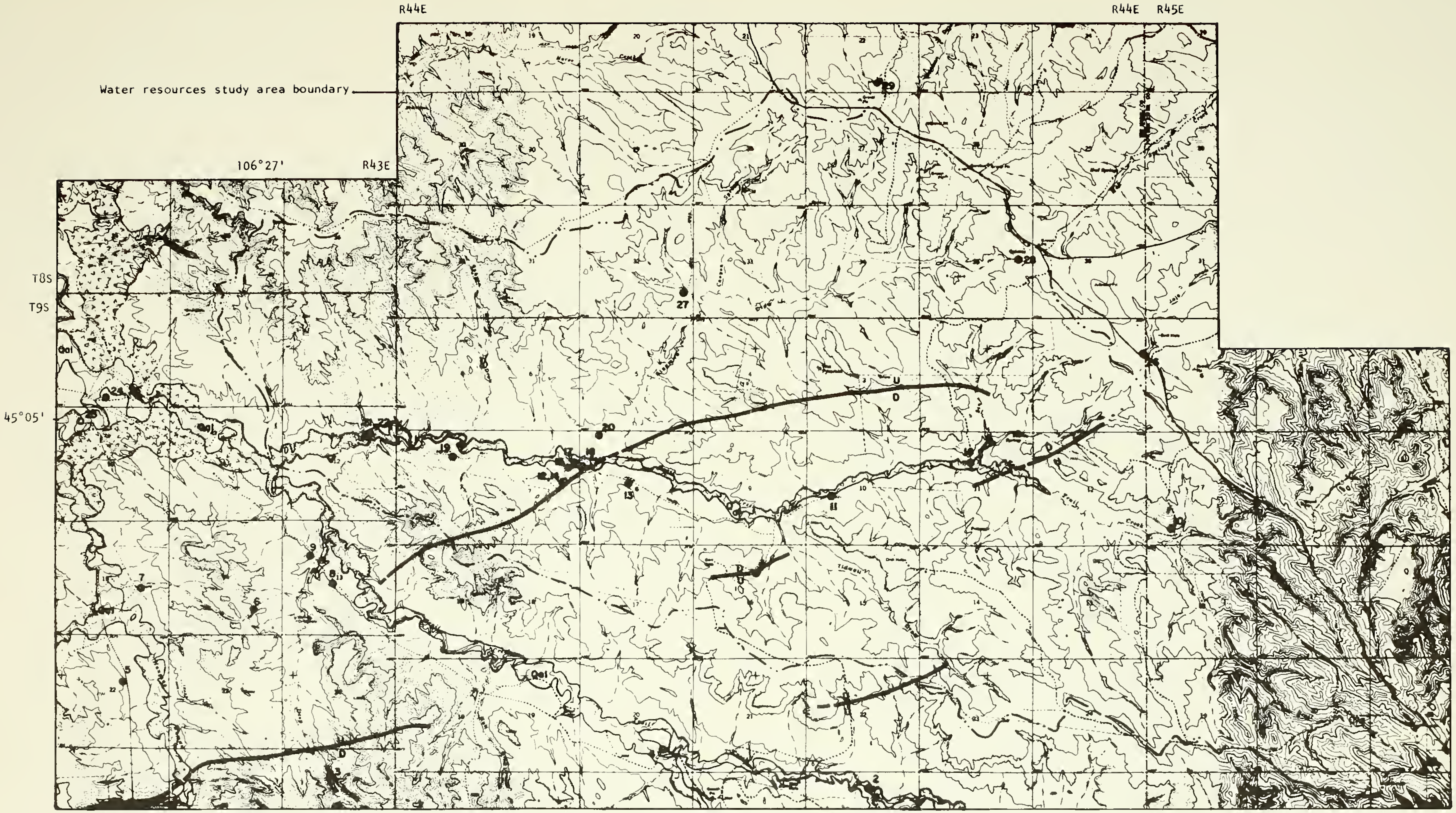
Ground-water data were collected from existing wells and springs inventoried during the summers of 1976 and 1977 and from 30 test wells drilled by the Montana Bureau of Mines and Geology in 1974, 1976, and 1977. Hydrologic boundaries and properties of shallow aquifers, principal direction of water movement, and water chemistry were determined from the data.

Further study will include long-term hydrologic monitoring to obtain a better understanding of the hydrologic system. In addition, a digital model will be constructed to quantitatively analyze water problems that could occur from specific mine plans.

Surface Water

Three flumes having continuous recorders and one stream-gaging station (East Trail Creek near Otter) were installed at the study area in November 1976 to monitor surface-water runoff and ground-water inflow and outflow along the drainage (Figure 37). Two rain gages subsequently were installed adjacent to the gaging station and the uppermost flume. Data from these instruments, together with data from neighboring stations, indicate that most streamflow occurs from February to June during spring runoff and spring storms.

Stream discharges of East Trail Creek near the Otter gaging station from February through October 1977 are shown on Figure 38. Also shown are the dissolved-solids concentrations of water from East Trail Creek and rainfall measurements for the period April 6 through October 1977. Strong correlation can be seen between periods of substantial rainfall in June and August and discharge at the gaging station located near the confluence of East Trail and Trail Creeks. Periods of smaller rainfall provided little runoff because of low antecedent soil-moisture conditions. Discharges in February, March, and April reflect periods of snowmelt. Discharges less than 0.1 ft^3/s (.003 m^3/s) are not shown on Figure 38.



Geology modified from Culbertson and Klett (unpublished mapping)

Datum is mean sea level.

EXPLANATION

HOLOCENE

Qal — ALLUVIUM - Mostly floodplain deposits of silt, clay, and fine gravel; and colluvium. Maximum thickness 40 feet.

CLINKER - Baked sandstone, siltstone and shale of Fort Union Formation produced by the burning of Anderson coal bed. Maximum thickness 50 feet.

EOCENE AND PALEOCENE

WASATCH FORMATION AND TONGUE RIVER MEMBER OF THE FORT UNION FORMATION sandstone, siltstone, shale, and coal.

Geologic contact. Dashed where concealed.

Fault. U, upthrown side; D, downthrown side; dashed where concealed.

Drainage boundary for East Trail Creek.

Gaging Station and Streamflow sampling site

Low-flow station.

WELL - closed circle indicates chemical analysis of water from Tongue River member of Fort Union Formation; open circle, alluvium. Number is identification from Tables 38 and 40.

Hanging Woman Creek Study Area

Location Map --

Surface-water station and chemical analysis sampling sites.

Figure 37

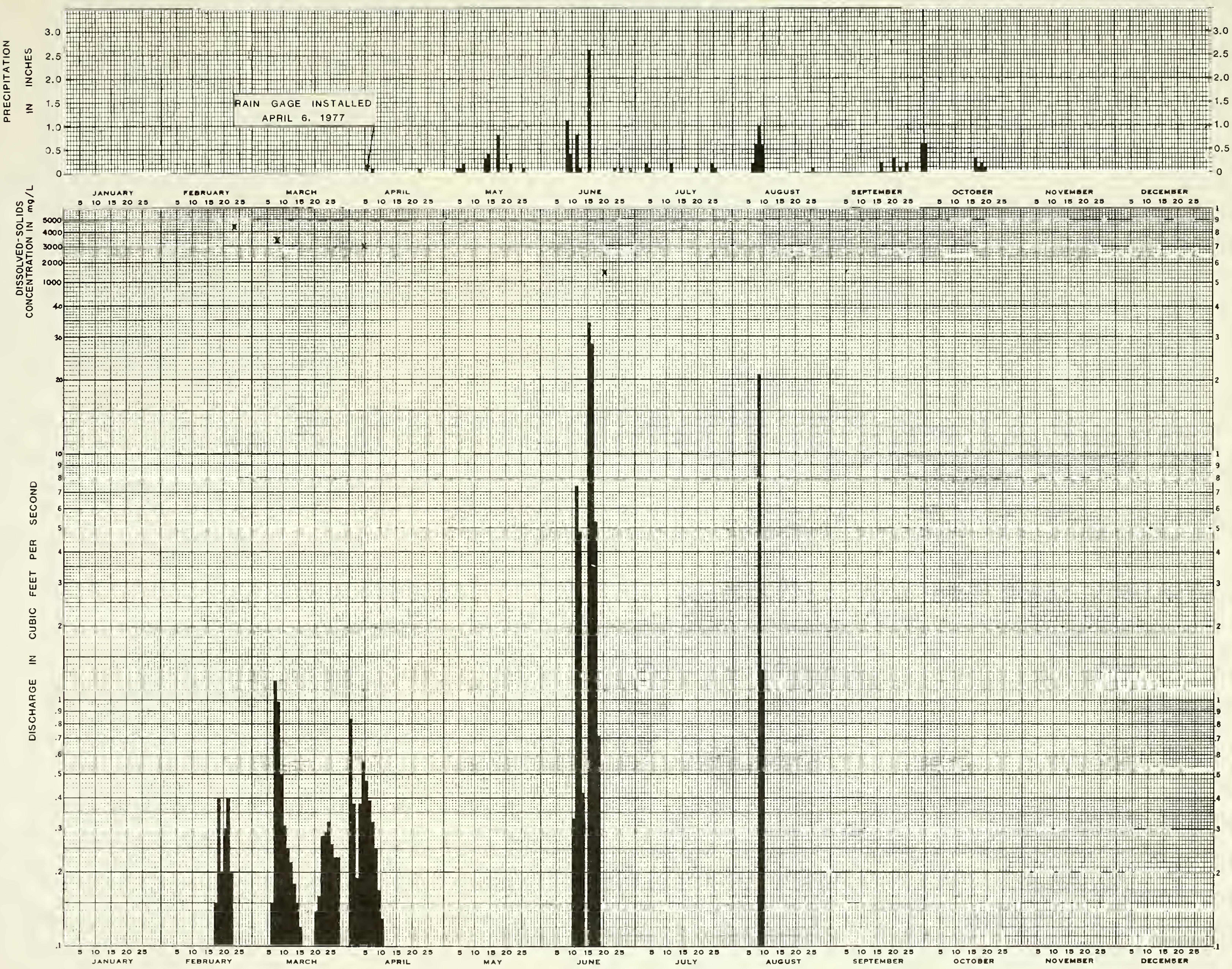


Figure 38. Precipitation and Stream Discharge, East Trail Creek near Otter.

Flow at the gage and the two downstream continuous recorder flumes receded to no flow rapidly after each rain. Flow measurements at the continuous recording flume farthest upstream show more persistent, but small, discharge. This is an indication that the lower reach of East Trail Creek is losing water from the stream channel to the ground-water system.

Fifteen perennial stock ponds are in the East Trail Creek basin; the largest (about 3 acres (1.21 ha)) is located in the N 1/2 Section 6, T9S, R44E (Figure 37). Together with four ephemeral stock ponds and several spreader dikes, these features can increase infiltration of water in the basin. Additional study would be necessary to determine infiltration amounts and significant sediment-trapping effects.

The mean annual flood of East Trail Creek was estimated from the size of the drainage area, the main channel slope, and the average annual precipitation to be about 100 ft^3/s (2.8 m^3/s). The 25-year and 100-year floods are about 700 and 1,250 ft^3/s (19.8 and 35.4 m^3/s), respectively.

Continued data collection and interpretation are necessary to define annual low-flow surface-water and ground-water interrelationships. In addition, although this basin is not instrumented for rainfall-runoff research, certain gross basin characteristics could be determined with this single gaging station and rainfall recorder.

Surface-Water Quality

Water samples collected from the East Trail Creek near Otter water-quality station (Figure 37) have been analyzed for common ions, and heavy metals (Table 37). Most streamflow at this station is open-channel discharge from the basin. Therefore, the water composition is characteristic of ions available for solution from the surficial material of the basin. Predominant ionic constituents are sodium, magnesium, and sulfate. Water samples analyzed from this station contain relatively small amounts of heavy metals. No concentrations of major constituents or metals are abnormally high for streamflow in this region, but the period of record for water-quality measurements is not yet long enough to make any meaningful water-quality interpretations.

Although the character of water at the sampling site is generally consistent with time, slight variations in dissolved-solids concentrations result from local surface runoff and changes in evapotranspiration conditions. Concentrations are expected to be lowest during periods of snowmelt runoff or during streamflow recession after storms when base flow is diluted (Figure 38). Storm runoff dissolves salts that have precipitated along drainage banks during seasonally dry periods, thereby temporarily increasing the dissolved-solids concentration.

Provisional instantaneous flow data, together with measured sediment concentrations at the time chemical samples were taken, indicate generally

Table 37.--Chemical and spectrographic analyses of water samples from East Trail Creek near Otter, Montana.

DATE	TIME	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	AIR TEMPERATURE (DEG C)	TEMPERATURE (DEG C)	TURBIDITY (JTU)	DISSOLVED OXYGEN (MG/L)	PERCENT SATURATION	BIOCHEMICAL OXYGEN DEMAND 5 DAY (MG/L)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)
FEB 23...	1045	5880	8.0	2.0	.5	3	8.3	64	--	2000	1500
MAR 08...	1230	4100	8.1	12.0	.0	3	3.9	30	--	1500	1100
APR 05...	1130	2650	8.3	13.0	7.5	6	9.0	86	1.4	1300	920
JUN 21...	1500	2225	8.2	20.5	18.0	20	--	--	--	690	430

DATE	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	PERCENT SODIUM	SODIUM ADSORPTION RATIO	DISSOLVED POTASSIUM (K) (MG/L)	BICARBONATE (HCO3) (MG/L)	CARBONATE (CO3) (MG/L)	ALKALINITY AS CACO3 (MG/L)	CARBON DIOXIDE (CO2) (MG/L)	DISSOLVED SULFATE (SO4) (MG/L)
FEB 23...	220	340	710	44	7.0	13	602	0	494	9.6	2900
MAR 08...	180	250	540	44	6.1	12	480	0	394	6.1	2200
APR 05...	160	210	490	46	6.0	8.0	416	0	340	3.3	2000
JUN 21...	110	100	230	42	3.8	9.1	310	0	250	3.1	890

DATE	DISSOLVED CHLORIDE (CL) (MG/L)	DISSOLVED FLUORIDE (F) (MG/L)	DISSOLVED SILICA (SIO2) (MG/L)	DISSOLVED SOLIDS (SUM OF CONSTITUENTS) (MG/L)	DISSOLVED SOLIDS (TONS PER AC-FT)	DISSOLVED SOLIDS (TONS PER DAY)	TOTAL NITRITE PLUS NITRATE (N) (MG/L)	TOTAL AMMONIA NITROGEN (N) (MG/L)	TOTAL ORGANIC NITROGEN (N) (MG/L)	TOTAL KJELDAHL NITROGEN (N) (MG/L)	TOTAL NITROGEN (N) (MG/L)
FEB 23...	19	.2	8.4	4510	6.13	2.07	.07	.01	.46	.47	.54
MAR 08...	16	.3	6.3	3440	4.68	22.3	.03	.03	.82	.85	.88
APR 05...	9.9	.2	3.0	3090	4.20	3.84	.01	.01	.61	.62	.63
JUN 21...	5.8	.3	3.6	1500	2.04	.40	.03	.08	.62	.70	.73

DATE	TOTAL NITROGEN (NO3) (MG/L)	TOTAL PHOSPHORUS (P) (MG/L)	DISSOLVED ALUMINUM (AL) (UG/L)	DISSOLVED ARSENIC (AS) (UG/L)	DISSOLVED BERYLLIUM (BE) (UG/L)	DISSOLVED BORON (B) (UG/L)	DISSOLVED CADMIUM (CD) (UG/L)	DISSOLVED CHROMIUM (CR) (UG/L)	DISSOLVED COPPER (CU) (UG/L)	DISSOLVED IRON (FE) (UG/L)	DISSOLVED LEAD (PB) (UG/L)
FEB 23...	2.4	.09	20	1	0	150	1	0	6	80	1
MAR 08...	3.9	.10	--	--	--	120	--	--	--	110	--
APR 05...	2.8	.02	--	--	--	120	--	--	--	70	--
JUN 21...	3.2	.06	20	1	0	120	2	20	2	210	5

DATE	DISSOLVED LITHIUM (LI) (UG/L)	DISSOLVED MANGANESE (MN) (UG/L)	DISSOLVED MERCURY (HG) (UG/L)	DISSOLVED MOLYBDENUM (MO) (UG/L)	DISSOLVED NICKEL (NI) (UG/L)	DISSOLVED SELENIUM (SE) (UG/L)	DISSOLVED VANADIUM (V) (UG/L)	DISSOLVED ZINC (ZN) (UG/L)	SURFACE AREA (SQUARE MILES)
FEB 23...	190	650	.0	1	7	1	.0	30	31
MAR 08...	--	--	--	--	--	--	--	--	31
APR 05...	--	--	--	--	--	--	--	--	31
JUN 21...	70	310	.0	1	10	1	.0	20	31

Table 38.-Location and quick reference to wells and springs cited in the East Trail Creek report.

STATION NAME	USE OR SPECIAL NUMBER	PERFORATED ZONE	LITHOLOGIC LOG OF WELL [a]	HYDROLOGIC DATA [b]	CHEMICAL QUALITY DATA [c]
08S44E19CBBB 1	HWC-04	(DIETZ)			
08S44E19CBBB 2	HWC-05	(ANDERSON)			
08S44E22DCDB	STOCK WELL	(COMPOSITE)			29
08S44E27CCCC	SPRING	(SANDSTONE)			
08S44E32DDAB	HWC-28	(ANDERSON)	X	X	27
08S44E35ADDC	STOCK WELL	(COMPOSITE)			28
09S43E02BBBB 1	HWC-21	(DIETZ)	X	X	
09S43E02BBBB 2	HWC-22	(ANDERSON)	X		
09S43E03CDDA 1	HWC-02	(CANYON)	X	X	24
09S43E03CDDA 2	HWC-03	(DIETZ)	X	X	25
09S43E10BBAD	STOCK WELL	(ALLUVIUM)			23
09S43E11ACBB	STOCK WELL	(ALLUVIUM)			
09S43E12ABDD 1	HWC-35	(ANDERSON & ALLVM)	X		21
09S43E12ABDD 2	HWC-36	(ALLUVIUM)	X	X	22
09S43E12ADBB 1	HWC-37	(ALLUVIUM)	X	X	
09S43E12ADBB 2	HWC-38	(ALLUVIUM)	X		
09S43E12ADBD	HWC-39	(ALLUVIUM)	X		
09S43E13BDBB	HWC-17	(ANDERSON)	X	X	9
09S43E13CAAA 1	HWC-06	(DIETZ)			
09S43E13CAAA 2	HWC-07	(ANDERSON)			8
09S43E14DBBB	HWC-27	(ANDERSON)	X	X	
09S43E15CDAB	STOCK WELL	(ALLUVIUM)			
09S43E15DABC	STOCK WELL				7
09S43E22ACCA	HWC-15	(ANDERSON)	X	X	5
09S43E25BADC	STOCK SPR.	(COMPOSITE)			3
09S43E27CDCA	STOCK WELL				1
09S43E27DABB	HWC-16	(ANDERSON)	X	X	
09S44E01ADAA	STOCK WELL	(ANDERSON)			26
09S44E06BBBB 1	HWC-23	(ANDERSON)	X		
09S44E06BBBB 2	HWC-24	(DIETZ)	X		
09S44E07ADAA 1	STOCK WELL	(ANDERSON & ALLVM)			18
09S44E07ADAA 2	HWC-32	(ALLUVIUM)	X		
09S44E07ADAB	HWC-33	(ALLUVIUM)	X		17
09S44E07ADAC	HWC-34	(ALLUVIUM)	X	X	15
09S44E07ADCD	HWC-20	(ANDERSON)	X	X	14
09S44E07ADDC 1	HWC-08	(DIETZ)		X	12
09S44E07ADDC 2	HWC-09	(ANDERSON)			
09S44E07BBCC 1	HWC-29	(ANDERSON)	X	X	19
09S44E07BBCC 2	HWC-29A	(ANDERSON)	X		
09S44E07BBCC 3	HWC-29B	(ANDERSON)	X	X	
09S44E07BBCC 4	HWC-29C	(ANDERSON)	X		
09S44E08BBAB 1	HWC-25	(DIETZ)	X		
09S44E08BBAB 2	HWC-26	(ANDERSON)	X	X	20
09S44E08BDBB	SPRING	(ALLUVIUM)			
09S44E08BDDC	HWC-18	(ANDERSON)	X	X	13
09S44E09CBCA	HWC-31	(ALLUVIUM)	X		
09S44E09CCAB	HWC-30	(ANDERSON)	X		
09S44E10CBAD	STOCK WELL	(COMPOSITE)			11
09S44E11AAAD	SPRING	(SANDSTONE)			
09S44E11BDAA	STOCK WELL	(COMPOSITE)			16
09S44E16ACCB	HWC-19	(ANDERSON)	X		4
09S44E20DCAA	STOCK WELL	(DIETZ & SNDSTONE)			2
09S44E27ABCB	STOCK WELL	(COMPOSITE)			
09S45E07CCAD	STOCK WELL	(COAL)			10
09S45E18BDDD	SPRING	(SANDSTONE)			

[a] X indicates log listed in Appendix
[b] X indicates data in table 39 or figures 39 through 42
[c] Numeral is identification number in tables 40 and 41 or figure 44

low suspended-sediment discharge from the basin for the period of record. The calculated suspended-sediment discharges for February 23, March 8, April 5, and June 21 were 0.0, 0.06, 0.05, and 0.02 ton/d (0.0, 0.054, 0.045, 0.018 tonne/d), respectively. These suspended-sediment loads are well below the carrying capacity of East Trail Creek; however, the availability of sediment to streams is generally low at the time of snowmelt and during low flow.

Chemical-quality data collection will be continued to determine cyclic annual fluctuations and chemical characteristics of unusual storms within the basin.

Ground Water

Twenty-nine wells and springs were inventoried at the study area to aid in determining the geology and hydrology. Thirty additional observation wells were drilled to provide specific information on lithology, water levels, hydraulic properties of aquifers, and chemical quality of water. The lithologic descriptions of observations wells are listed in Appendix J. Table 38 gives a quick reference to wells and springs discussed in this report.

The East Trail Creek site is underlain by several aquifers. The shallowest aquifers are alluvium of Holocene age, Anderson clinker of Holocene (?) age, and the Tongue River Member of the Fort Union Formation of Paleocene age (Figure 15). The 240 (73 m) thick Lebo Shale Member of the Fort Union Formation separates the Tongue River Member from underlying aquifers, which include the Tullock Member of the Fort Union Formation, upper Hell Creek aquifer, Fox Hill's lower Hell Creek aquifer, Judith River Formation, Eagle Sandstone, Muddy Sandstone Member of the Thermopolis Shale, and Madison Group. Because the Lebo Shale has a low hydraulic conductivity, the underlying aquifers are not likely to be affected by surface mining at the site. The Wasatch Formation of Paleocene and Eocene age is present on ridges in the study area, but is unsaturated and is not considered in discussions of ground water.

The uppermost unconfined (water-table) aquifer at the study area consists of alluvium containing fine colluvium and coarser material along East Trail Creek. Alluvium occurs beneath the valley bottoms; colluvium, which is mostly unsaturated, mantles the Tongue River Member adjacent to the valleys.

Four test holes were drilled through the alluvium across East Trail Creek in the northeast quarter of Section 12, T9S, R43E, to determine saturated thickness and composition (Figure 39). The alluvium is mostly brown soft clay and fine gravel that contains silt and sand. The alluvium along the cross section has an average thickness of about 34 feet (10.3 m) and is bounded by gentle slopes of the Tongue River Member on the northwest and southeast. Water levels in the test holes show that the water table

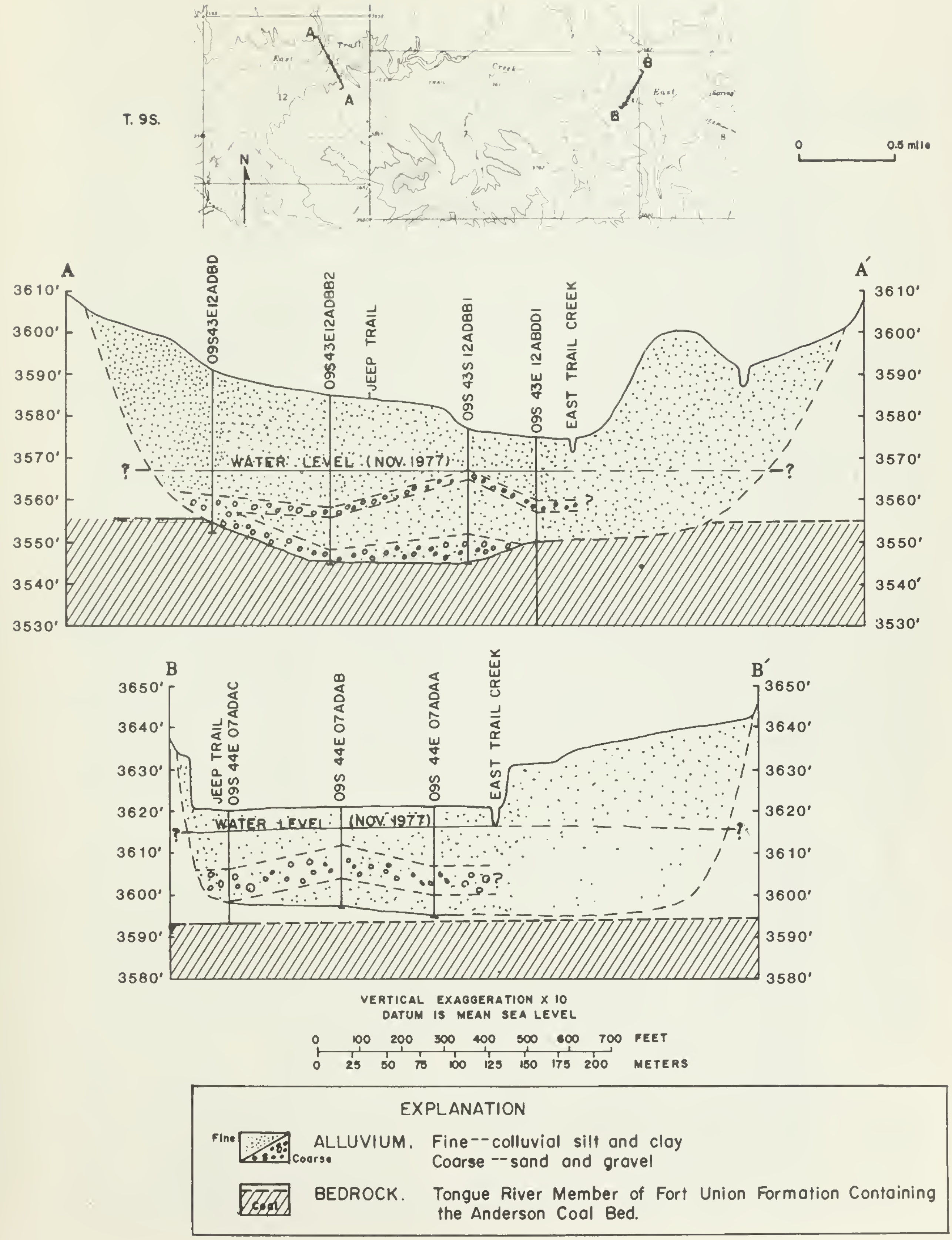


Figure 39. Geologic Sections across East Trail Creek.

is relatively flat in the alluvium. Measured water levels in wells tapping alluvium range from 7 feet (2.1 m) below land surface near the stream channels to 24 feet (7.3 m) on nearby slopes.

Three additional test holes were drilled through similar alluvium across East Trail Creek in the northwest quarter of Section 7, T9S, R43E. At this upstream section the alluvium thickness averages about 26 feet (8 m) and the water level ranges from 4 to 9 feet (1.2 to 2.7 m) below land surface.

The Tongue River Member contains a water-table aquifer and shallow confined-aquifer systems. This bedrock unit, which is composed mainly of shale, siltstone, fine-grained sandstone, and coal, is areally continuous throughout and beyond the limits of the study area. However, lenticular siltstone, sandstone, and channel sand within the Tongue River Member compose many confined and semi-confined aquifers that are not areally extensive. At the west edge of the study area, Tongue River rock units grade abruptly into clinker formed by burning of the Anderson coal bed (Figure 15).

The Anderson, Dietz, and Canyon coal beds, which occur within the Tongue River Member of the Fort Union Formation, appear to be the most continuous shallow aquifers penetrated by drill holes at the study site. These coal beds are generally confined above and below by black carbonaceous shale or clayey siltstone. The nearest hydrologic boundaries of the Dietz and Canyon coal beds are outcrops 12 to 15 miles (3.7 to 4.6 m) northeast of the study area. Part of the water in the Anderson discharges west through the clinker into alluvium along Trail Creek. The slightly folded Anderson generally plunges westward, extending in the subsurface to the Hanging Woman Creek and Tongue River valleys, which are discharge areas for water not discharged to the alluvium along East Trail and Trail Creek.

Hydrographs of two wells tapping the alluvium show small water-level declines during the summer of 1977 (Figure 40). Well 09S44E07ADAC, which is about 650 feet (198 m) from the stream channel, shows 1 1/2 feet (0.5 m) of water-level decline during the summer with no abrupt changes. Water in well 09S43E12ADBB1, which is about 400 feet (122 m) closer to East Trail Creek, declined more than twice as much. In addition, the storm of August 8-9 (Figure 38) dramatically impacts the water level in well 09S43E12ADBB1, but the impact is almost unseen in the other well. This result is due in part to its proximity to a nearby spring.

Hydrographs of wells tapping the progressively deeper Anderson coal (09S44E07BBCC3) and Deitz coal (09S44E07ADDC1) show progressively less change as these beds become confined and slightly stressed (Figure 40). The 8-foot (2.4 m) anomaly in water level of the Anderson well for late September reflects response to an aquifer test of well 09S44E07BBCC1 (Table 39). Water level in the Dietz well shows little change.

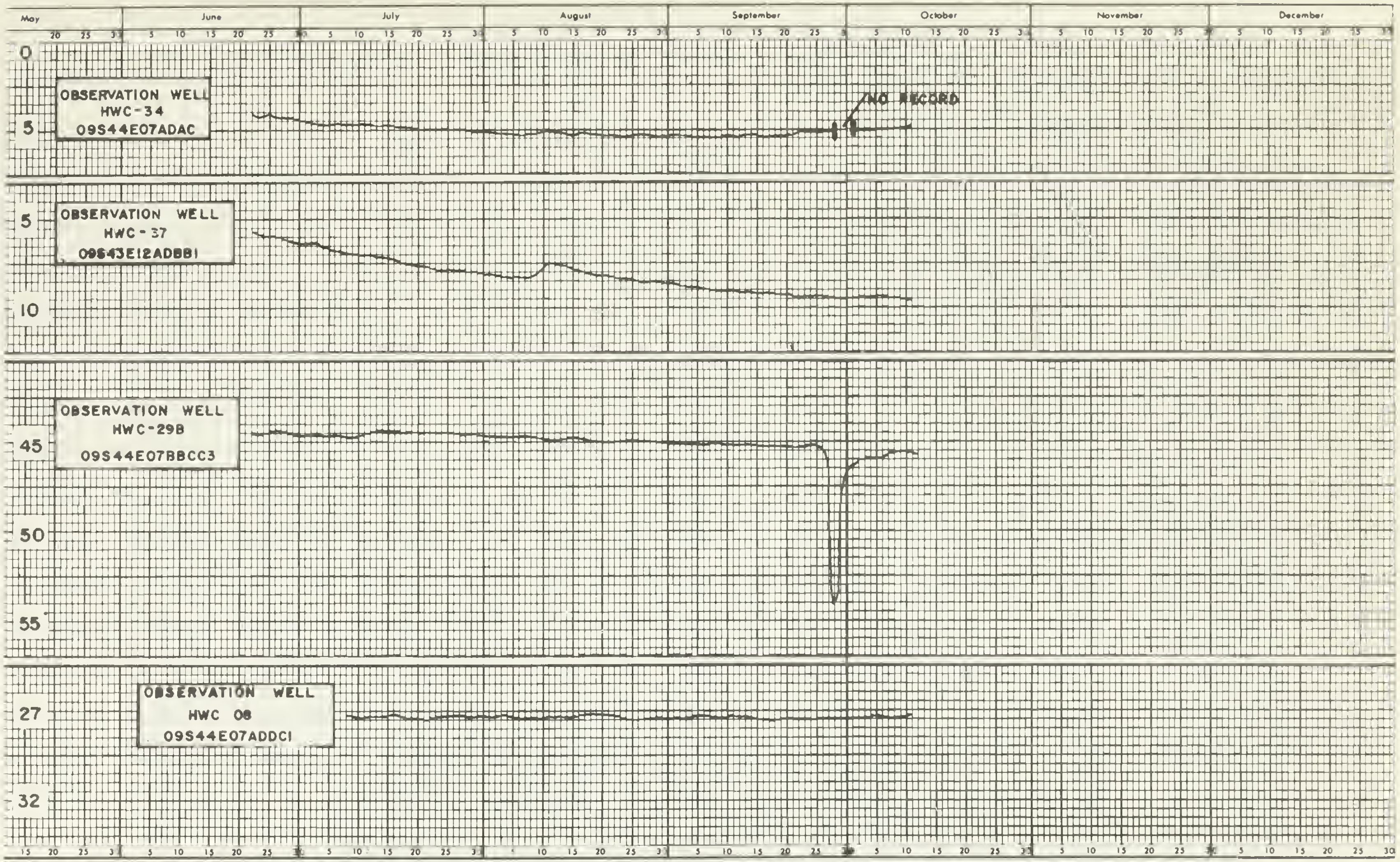


Figure 40. Hydrographs of Selected Observation Wells.

Table 39.--Aquifer-test results.

Location of pumped well	Date of test (M-D-Y)	Aquifer	Well discharge (gal/min)	Specific capacity [(gal/min)/ft]	Length of test (d)	Trans-miss-ivity (ft^2/d)	Hydraulic conduc-tivity (ft/d)	Coef-ficient of storage	Method of anal-ysis[1]	Remarks
08S44E32DDAB	07-07-77	Anderson	4.4	0.36	0.14	160	5.1	--	D,R,J	Gas release
09S43E03CDDA-1	06-10-75	Canyon	2.4	.25	.14	23	1.2	--	D, J	Gas release
09S43E03CDDA-2	10-08-74	Dietz	10.5	.25	.14	80	5.7	--	D,R,J	
09S43E12ABDD-2	09-19-77	Alluvium	4.4	.49	.54	1,250	83	$2.1x10^{-3}$	D,R,J.	Obs. well; r=174 ft
09S43E13BDBB	4-19-77	Anderson	6.9	.63	.13	33	1.4	--	D,B	
09S43E14DBBB	09-14-77	Anderson	2.9	.11	.73	43	1.5	--	R,J	
09S43E22ACCA	06-22-77	Anderson	10.0	.53	.17	280	10.8	--	D,J	
09S43E27DABB	09-13-77	Anderson	--	--	.11	18	.7	--	R,S	
09S44E07ADAC	09-29-77	Alluvium	17.7	--	.38	1,650	92	--	D,R,J	
09S44E07ADCD	04-26-77	Anderson	.3	.03	.21	3	.1	$4.4x10^{-5}$	D,J.	Obs. well; r=77 ft
09S44E07ADDC-1	04-28-77	Dietz	.3	.02	.03	1	.1	--	D,J.	Gas release
09S44E07BBCC-1	09-27-77	Anderson	3.0	.11	1.04	8	.3	$5.0x10^{-4}$	D,B	Obs. well; r=44 ft
09S44E08BBAB-2	04-21-77	Anderson	4.6	.68	.25	210	6.4	--	D,R,J	
09S44E08BDDC	04-28-77	Anderson	8.9	.30	.15	92	2.8	--	D,R,J	

[1]B, Boulton delayed yield; D, drawdown; J, Jacob method; R, recovery; S, slug bailer

The direction of water movement is generally perpendicular and down-gradient to the water-table contours. The gradient is steeper where the transmissivity is high. Water in the alluvium moves downvalley, but a large percentage is either evaporated from small ponds where the land surface intersects the water table or evaporated and transpired where the depth to water in the alluvium is shallow.

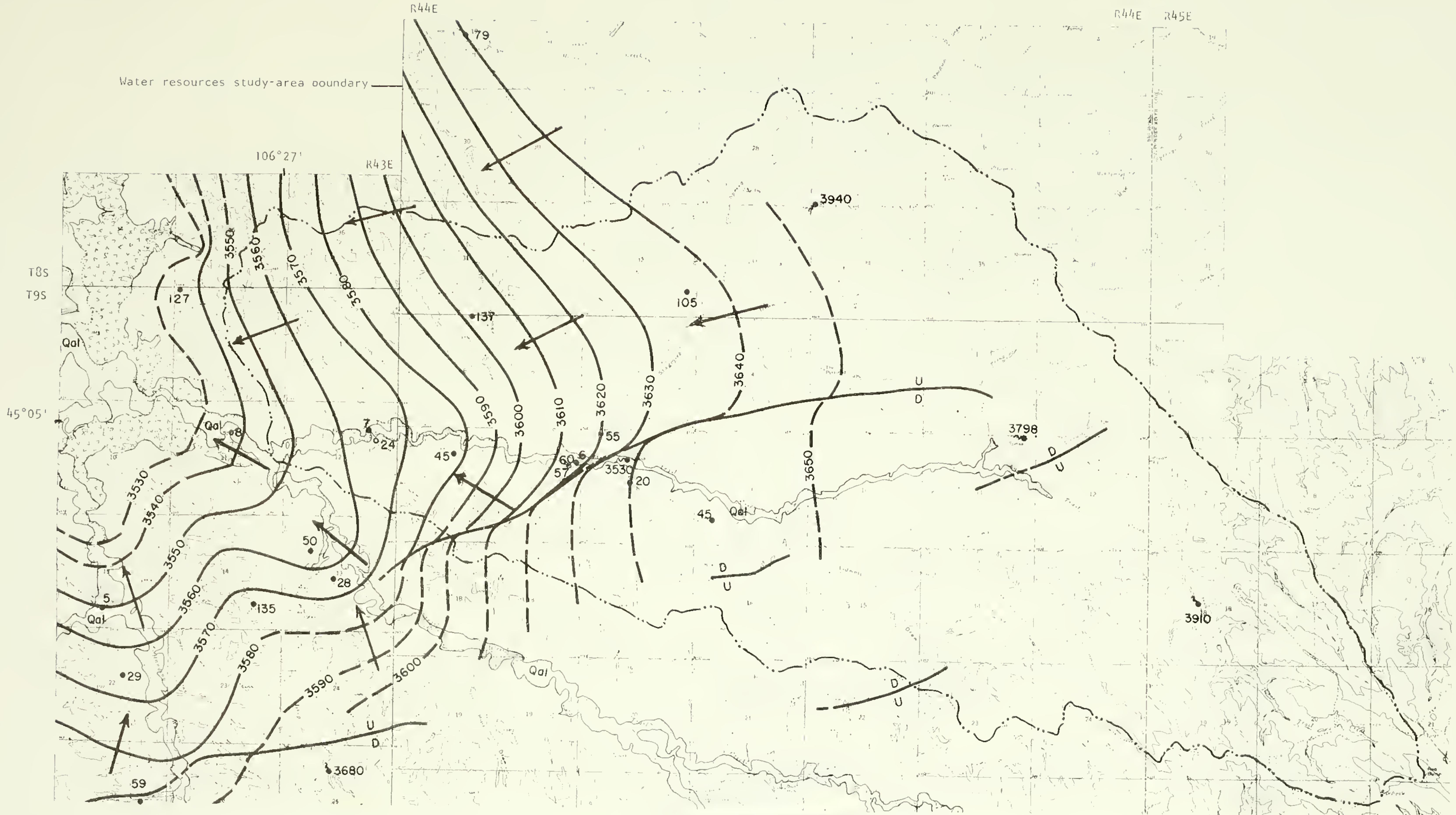
The potentiometric surface in the Anderson coal bed and adjacent alluvium (Figure 41) and in the Dietz coal bed (Figure 42) is a highly generalized reflection of the area topography. Few water levels are available from deep test wells along the divides in the East Trail Creek area. However, wells in high areas near the site generally have depths to water of 105 to 137 feet (32 to 42 m) below land surface, whereas depths to water along East Trail and Trail Creeks range from 6 to 60 feet (1.8 to 18 m) below land surface. The potentiometric surface of the Dietz coal-bed aquifer is similar to that for the upper aquifer but water levels are about 20 to 80 feet (6 to 24 m) lower (Figure 42). An area having progressively deeper water levels with progressively deeper aquifers is generally interpreted to be a recharge area.

The East Trail Creek fault apparently retards the flow of ground water as indicated by the spacing and position of local water-level contours (Figure 41). Water retarded upstream from the fault recharges stratigraphically lower aquifers across the fault. The 10-foot (3 m) head difference across the fault where it crosses the stream valley may be the result of the angle between the fault and the ground-water flow and/or hydraulic complexities across the fault. Springs located at 09S44E08BADC may also be fault-related. Data were unavailable south of the fault (Figure 42) so the effect of the fault upon the deeper Dietz coal-bed aquifer is unknown. The 10-foot (3 m) thick Dietz coal-bed aquifer is probably displaced and not continuous across the fault. Further study is necessary to determine deep cross-fault hydrologic relationships.

Drawdown and recovery tests were conducted by the Montana Bureau of Mines and Geology on 14 wells completed in the alluvium and the Anderson, Dietz, and Canyon coal beds (Table 39). Discharges during two tests on the alluvium were 4.4 and 17.7 gal/min (0.27 - 1.12 l/s); transmissivity averaged 1,450 ft^2/d (135 m^2/d). The storage coefficient of 2.1×10^{-3} computed for the alluvium is unreasonably low and may indicate confinement. Discharges during nine tests on the Anderson coal-bed aquifer ranged from 0.3 to 10.0 gal/min (0.02 to 0.63 l/s); transmissivity averaged about 90 ft^2/d (8 m^2/d). Storage coefficients from two tests averaged 2.7×10^{-4}. Discharges from three deeper tests in the Dietz and Canyon coal beds ranged from 0.3 to 10.5 gal/min (0.02 to .66 l/s); transmissivity averaged about 30 ft^2/d (2.8 m^2/d). No storage coefficient was calculated for the deeper coals.

The average velocity of ground-water flow can be estimated using a form of Darcy's law:

$$v = \frac{K\,dh/dl}{\theta}$$



Geology modified from Culbertson and Klett (unpublished mapping)

Datum is mean sea level.

EXPLANATION

HOLOCENE
- Qal — ALLUVIUM - Mostly floodplain deposits of silt, clay, and fine gravel; and colluvium. Maximum thickness 40 ft.
- CLINKER - Baked sandstone, siltstone and shale of Fort Union Formation produced by the burning of Anderson coal. Maximum thickness 50 ft.

EOCENE AND PALEOCENE
- WASATCH FORMATION AND TONGUE RIVER MEMBER OF THE FORT UNION FORMATION sandstone, siltstone, chale, and coal

Geologic contact. Dashed where concealed.

Fault. U, upthrown side; D, downthrown side; dashed where concealed.

3590 — POTENTIOMETRIC CONTOUR - shows altitude of water surface in Anderson coalbed and alluvium near Anderson coal outcrop. Dashed where approximately located. Contour interval is 10 feet. Datum is mean sea level.

45 — TEST WELL or STOCK WELL - Number is depth to water, in feet below land surface, 1973-77. Well obtains water from Anderson coal bed.

8 — TEST WELL or STOCK WELL - Number is depth to water, in feet below land surface, 1973-77. Well obtains water from alluvium near Anderson coal outcrop.

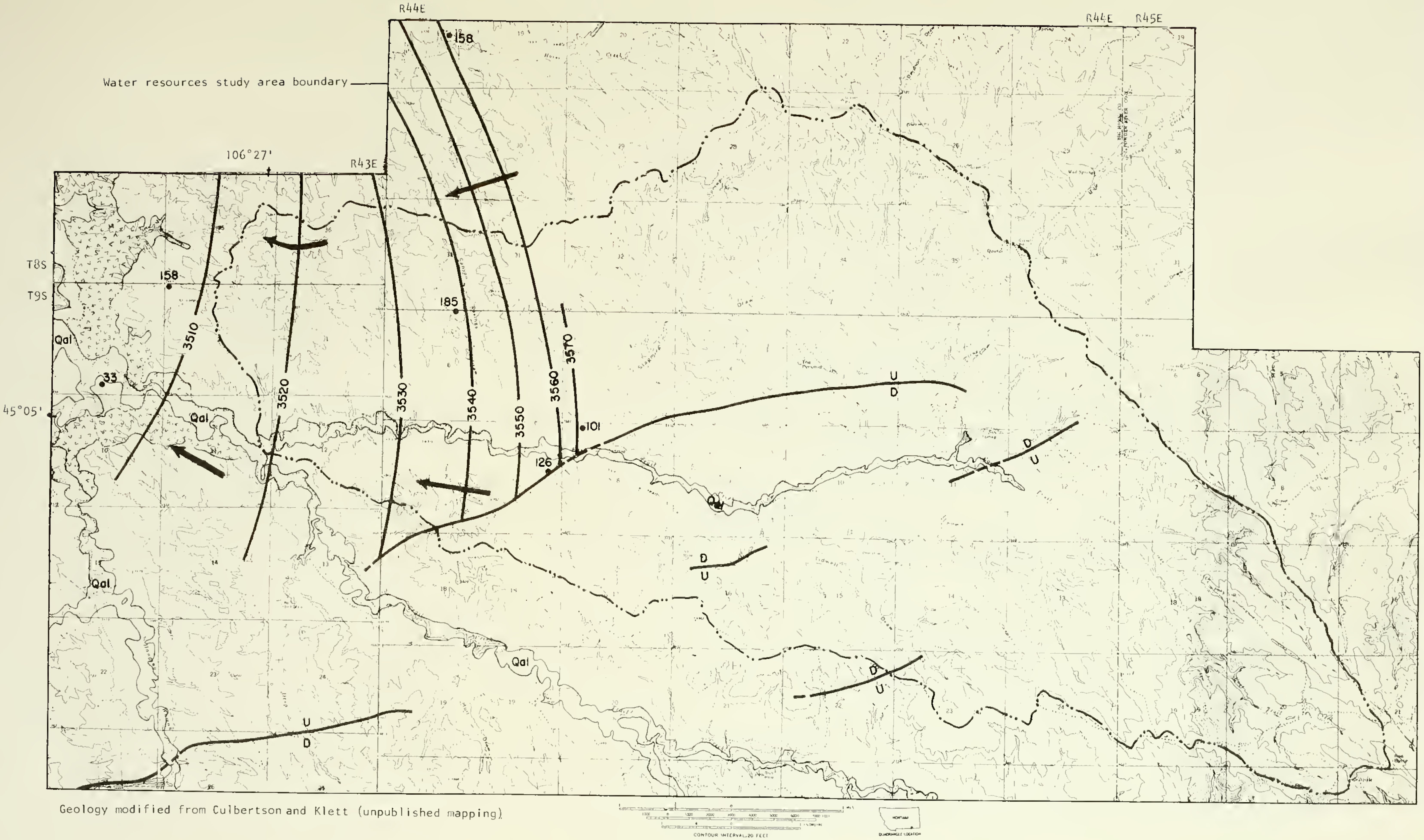
SPRING or SEEP - Number is altitude of land surface. Datum is mean sea level.

DIRECTION of water movement in Anderson coal bed.

Hanging Woman Creek Study Area

Hydrogeologic Map showing Potentiometric surface of Anderson coalbed and adjacent alluvium.

Figure 41



EXPLANATION

Datum is mean sea level.

HOLOCENE

Qal ALLUVIUM - Mostly floodplain deposits of silt, clay, and fine gravel; and colluvium. Maximum thickness 40 feet.

CLINKER - Baked sandstone, siltstone and shale of Fort Union Formation produced by the burning of Anderson coal bed. Maximum thickness 50 feet.

EOCENE AND PALEOCENE

WASATCH FORMATION AND TONGUE RIVER MEMBER OF THE FORT UNION FORMATION sandstone, siltstone, shale, and coal.

Geologic contact. Dashed where concealed.

U/D Fault. U, upthrown side; D, downthrown side; dashed where concealed.

3530 POTENTIOMETRIC CONTOUR - Shows altitude of water surface in Dietz coal bed. Contour interval is 10 feet. Datum is mean sea level.

•158 TEST WELL - Number is depth to water, in feet below land surface, 1974-77. Well obtains water from Dietz coal bed.

DIRECTION of water movement in Dietz coal bed.

Hanging Woman Creek Study Area

Hydrogeologic Map showing Potentiometric surface of Dietz coal bed.

Figure 42

where:

v = average velocity in feet per day
K = hydraulic conductivity in feet per day
dh/dl = gradient, unit change in head per unit length of flow, and
θ = porosity as a decimal fraction

Using an average hydraulic conductivity (K) of 88 ft/d (27 m/d) determined from aquifer tests on the alluvium, an average gradient of 40 ft/mi (7.5 m/km) from Figure 41)), and an estimated porosity of 0.20, the average velocity of water passing through the alluvium is estimated to be about 3.3 ft/d (1 m/d). Using an average K of 3.0 ft/d (.9 m/d) determined from aquifer tests on the coal-bed aquifers, an average gradient of 15 ft/mi (2.8 m/km) (Figure 42) and an estimated coal porosity of 0.02, the average velocity of water flowing through the coals is estimated to be about 0.4 ft/d (0.1 m/d). These estimates assume average conditions and are not valid for predicting the velocities of contaminants passing through the same material, because contaminants may travel along preferential pathways not typified by average conditions. However, the velocities do indicate average flow rates and are useful in evaluating probable rate of movement.

Ground-Water Quality

Chemical, heavy-metals, and radiochemical analyses of water from the upper part of the Tongue River Member of the Fort Union Formation in the vicinity of the study area are listed in Table 40. The water samples were collected from 1 developed spring, 12 stock wells, and 16 test wells that tap single or multiple aquifer units of sandstone or coal. Sampling depths range from land surface at springs to 273 feet (83 m) at the deepest well; dissolved-solids concentrations for all samples of ground water range from 438 to 9,460 mg/l (milligrams per liter).

The U.S. Public Health Service (1962) has established the following drinking water standards. The concentrations are recommended maximums unless water of no better quality is available.

Substance	Concentration, in milligrams per liter
Chloride (Cl)	250
Copper (Cu)	1
Iron (Fe)	.3
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Dissolved solids	500
Zinc (Zn)	5
Manganese (Mn)	.05

Table 40.--Chemical, heavy metals, and radiochemical analyses of ground water from the vicinity of the Hanging Woman Creek study area.

IDENTIFICATION NUMBER	STATION NAME		DATE OF SAMPLE	TIME	SAMP-LING DEPTH (FT)	TOTAL DEPTH OF WELL (FT)	ELEV. OF LAND SURFACE DATUM (FT. ABOVE MSL)
1	09S43E27CDCA STOCK WELL	057	73-10-28	1630	--	--	3760
2	09S44E27ABCB STOCK WELL (ALLUVIUM)	057	75-06-04	1700	34	54	3717
3	09S43E25BADC STOCK SPR. (COMPOSITE)	057	74-02-28	1650	.0	--	3680
4	09S44E20DCAA STOCK WELL (DIETZ & SNDSTONE)	057	75-06-04	1600	184	204	3650
5	09S43E22ACCA HWC-15 (ANDERSON)	057	77-06-23	1210	--	129	3595
	09S43E22ACCA HWC-15 (ANDERSON)	057	77-06-23	1215	--	129	3595
6	09S43E14DBBB HWC-27 (ANDERSON)	057	77-07-08	1200	231	264	3710
	09S43E14DBBB HWC-27 (ANDERSON)	057	77-07-08	1400	231	264	3710
7	09S43E15DABC STOCK WELL	057	73-10-28	1400	--	--	3579
8	09S43E13CAAA 2 HWC-07 (ANDERSON)	057	77-04-29	1000	37	66	3590
	09S43E13CAAA 2 HWC-07 (ANDERSON)	057	77-04-29	1200	37	66	3590
9	09S43E13BDBB HWC-17 (ANDERSON)	057	77-04-19	1000	60	82	3604
	09S43E13BDBB HWC-17 (ANDERSON)	057	77-04-27	1730	60	82	3604
10	09S45E07CCAD STOCK WELL (COAL)	057	74-02-02	1450	--	285	3900
	09S45E07CCAD STOCK WELL (COAL)	057	75-06-26	1330	273	285	3900
11	09S44E10CBAD STOCK WELL (ALLUVIUM)	057	75-06-04	1830	29	50	3721
12	09S44E07ADDC 1 HWC-08 (DIETZ)	057	77-04-28	0940	170	200	3679
	09S44E07ADDC 1 HWC-08 (DIETZ)	057	77-04-28	1000	170	200	3679
13	09S44E08BDDC HWC-18 (ANDERSON)	057	77-04-28	1000	100	243	3670
	09S44E08BDDC HWC-18 (ANDERSON)	057	77-04-28	1630	100	243	3670
14	09S44E07ADCD HWC-20 (ANDERSON)	057	77-04-26	1000	80	132	3676
	09S44E07ADCD HWC-20 (ANDERSON)	057	77-04-26	1200	80	132	3676
15	09S44E07ADAC HWC-34 (ALLUVIUM)	057	77-09-29	2140	--	27	3621
16	09S44E11BDAA STOCK WELL (COMPOSITE)	057	75-06-03	1100	--	180	3791
17	09S44E07ADAB HWC-33 (ALLUVIUM)	057	77-09-13	1000	--	24	3621
18	09S44E07ADAA 1 STOCK WELL (ANDERSON & ALLVM)	057	74-02-28	1140	40	70	3623
	09S44E07ADAA 1 STOCK WELL (ANDERSON & ALLVM)	057	77-04-28	1130	40	70	3623
19	09S44E07BBCC 1 HWC-29 (ANDERSON)	057	77-09-27	1340	--	94	3620
20	09S44E08BBAB 2 HWC-26 (ANDERSON)	057	77-04-28	1000	73	110	3675
21	09S43E12ABDD 1 HWC-35 (ANDERSON & ALLVM)	057	77-06-21	1300	27	61	3575
	09S43E12ABDD 1 HWC-35 (ANDERSON & ALLVM)	057	77-06-21	1400	27	61	3575
22	09S43E12ABDD 2 HWC-36 (ALLUVIUM)	057	77-06-21	1500	12	22	3575
	09S43E12ABDD 2 HWC-36 (ALLUVIUM)	057	77-06-21	1600	12	22	3575
	09S43E12ABDD 2 HWC-36 (ALLUVIUM)	057	77-09-20	0700	--	22	3575
23	09S43E10BBAD STOCK WELL (ALLUVIUM)	057	74-02-26	1420	--	75	3520
24	09S43E03CDDA 1 HWC-02 (CANYON)	057	75-06-16	1400	100	296	3542
25	09S43E03CDDA 2 HWC-03 (DIETZ)	057	75-06-16	1500	60	108	3539
	09S43E03CDDA 2 HWC-03 (DIETZ)	057	76-06-09	1200	100	108	3539
26	09S44E01ADAA STOCK WELL (ANDERSON)	057	74-02-28	1830	--	330	4000
27	08S44E32DDAB HWC-28 (ANDERSON)	057	77-07-06	1240	147	183	3738
	08S44E32DDAB HWC-28 (ANDERSON)	057	77-07-07	1200	147	183	3738
28	08S44E35ADDC STOCK WELL (COMPOSITE)	057	74-02-03	1115	--	28	4016
	08S44E35ADDC STOCK WELL (COMPOSITE)	057	75-06-19	1000	--	28	4016
29	08S44E22DCDB STOCK WELL (COMPOSITE)	057	75-06-19	1000	--	190	4109

Table 40.--Chemical, heavy metals, and radiochemical analyses of ground water from the vicinity of the Hanging Woman Creek study area.--continued

IDENTIFICATION NUMBER	FLOW RATE (GPM)	SPECIFIC CONDUCTANCE (MICROMHOS)	PH (UNITS)	TEMPERATURE (DEG C)	TURBIDITY (JTU)	HARDNESS (CA,MG) (MG/L)	NONCARBONATE HARDNESS (MG/L)	DISSOLVED CALCIUM (CA) (MG/L)	DISSOLVED MAGNESIUM (MG) (MG/L)	DISSOLVED SODIUM (NA) (MG/L)	PERCENT SODIUM	SODIUM ADSORPTION RATIO
1	--	1900	8.2	11.0	--	30	0	5.5	4.0	500	97	39
2	7.0	7270	7.7	8.0	--	2300	1700	380	330	930	47	8.4
3	.50	777	7.3	4.8	--	380	100	64	53	27	13	.6
4	4.5	8560	7.8	8.0	--	2800	2100	380	450	1120	46	9.2
5	10	2170	8.5	13.0	--	28	0	5.2	3.5	560	97	46
	--	--	--	--	--	--	--	--	--	--	--	--
6	1.0	--	7.8	--	--	--	--	--	--	--	--	--
	1.0	3740	7.8	18.5	--	96	0	19	12	900	95	40
7	--	2250	6.8	10.0	--	32	0	5.7	4.4	640	97	49
8	2.0	5940	7.5	13.5	--	1100	130	170	170	1200	70	16
	1.8	6080	7.2	13.7	--	1100	160	170	170	1200	70	16
9	7.0	2500	7.5	12.0	--	730	160	99	120	720	68	12
	3.0	3920	7.0	13.5	--	770	220	110	120	700	66	11
10	--	1990	8.1	12.0	--	40	0	9.8	3.8	530	96	37
	10	2150	8.0	12.5	2	39	0	8.9	4.0	520	96	36
11	--	7520	7.9	9.0	--	2600	2000	270	460	910	43	7.8
12	.30	2530	7.9	--	--	47	0	9.4	5.5	660	96	42
	.30	2520	8.2	6.5	--	44	0	8.7	5.5	650	96	42
13	9.0	2220	8.2	12.5	--	33	0	6.3	4.2	580	97	44
	9.0	2230	7.8	12.8	--	34	0	6.8	4.1	590	97	44
14	.30	2760	8.3	13.0	--	54	0	10	7.1	660	96	39
	.30	2730	7.7	12.5	--	59	0	12	6.8	730	96	42
15	17	5170	7.6	10.5	--	2100	1500	280	330	700	42	6.7
16	2.0	980	7.7	10.5	--	480	210	72	72	35	14	.7
17	2.0	4410	7.8	--	--	1800	1200	240	300	540	39	5.5
18	--	4960	7.5	7.5	--	2000	1500	280	320	620	40	6.0
	4.0	5650	7.3	7.5	--	2400	1800	320	380	540	33	4.8
19	3.0	9940	7.3	13.5	--	3300	2500	490	500	1800	54	14
20	4.6	4840	7.6	12.5	--	1200	52	180	180	880	61	11
21	2.0	6030	7.5	12.0	--	2200	1500	260	380	880	46	8.0
	2.0	--	7.2	12.0	--	--	--	--	--	--	--	--
22	6.0	6480	7.7	10.5	--	2600	1900	330	440	930	43	8.0
	6.0	--	7.2	10.5	--	--	--	--	--	--	--	--
	4.4	6420	7.7	9.5	--	2500	1800	300	420	960	46	8.0
23	5.0	5450	7.2	9.5	--	1700	1300	270	260	810	50	8.4
24	--	2670	8.1	12.0	120	41	0	6.0	6.1	640	97	44
25	--	10500	8.1	11.5	37	680	0	57	130	1900	86	32
	--	10500	8.3	12.0	15	490	0	110	50	1900	89	38
26	--	2530	8.6	12.0	--	48	0	11	4.9	650	96	41
27	4.0	2690	7.8	15.0	--	53	0	10	6.7	700	96	42
	4.0	--	7.5	15.0	--	--	--	--	--	-	--	--
28	--	750	7.8	9.5	--	390	44	79	48	20	10	.4
	10	742	7.3	10.0	--	390	44	80	46	17	9	.4
29	5.0	944	7.3	11.0	--	460	210	57	76	38	15	.8

Table 40.--Chemical, heavy metals, and radiochemical analyses of ground water from the vicinity of the Hanging Woman Creek study area.--continued

IDENTIFICATION NUMBER	DIS-SOLVED PO-TAS-SIUM (K) (MG/L)	BICAR-BONATE (HCO3) (MG/L)	CAR-BONATE (CO3) (MG/L)	ALKA-LINITY AS CACO3 (MG/L)	CARBON DIOXIDE (CO2) (MG/L)	TOTAL SUL-FIDE (S) (MG/L)	DIS-SOLVED SULFATE (SO4) (MG/L)	DIS-SOLVED CHLO-RIDE (CL) (MG/L)	DIS-SOLVED FLUO-RIDE (F) (MG/L)	BROMIDE (BR) (MG/L)	IODIDE (I) (MG/L)	DIS-SOLVED SILICA (SIO2) (MG/L)
1	3.7	1262	0	1035	13	--	45	22	1.1	--	--	7.6
2	7.9	756	0	620	24	--	3600	14	.3	--	--	11
3	1.5	336	0	276	27	--	150	4.9	.6	--	--	12
4	12	854	0	701	22	--	4400	29	.4	--	--	12
5	4.3	1550	9	1290	7.9	--	.3	16	2.1	--	--	9.2
	--	--	--	--	--	.4	--	--	--	--	--	--
6	--	--	--	--	--	1.1	--	--	--	--	--	--
	6.4	1150	0	946	29	--	1100	18	1.4	--	--	8.6
7	4.8	1490	79	1480	4.2	--	59	19	.9	--	--	7.7
8	13	1180	0	968	60	--	2700	47	.6	--	--	10
	14	1180	0	970	119	.8	2800	17	.8	.2	.01	13
9	10	694	0	569	35	--	1600	16	.6	--	--	11
	11	670	0	550	107	.7	1700	13	1.0	.1	.00	11
10	3.9	1420	0	1160	18	--	.8	15	2.0	--	--	8.4
	5.0	1420	0	1160	23	--	5.5	17	2.0	--	--	8.5
11	7.8	716	0	588	14	--	3800	18	.3	--	--	10
12	5.8	1720	0	1410	35	.6	43	25	1.7	.0	.01	10
	5.7	1740	0	1430	18	--	45	26	1.5	--	--	9.6
13	4.4	1590	0	1310	16	--	.3	24	1.7	--	--	9.7
	4.5	1570	0	1290	40	.5	9.2	24	1.8	.0	.01	12
14	5.1	1890	7	1560	15	--	61	36	1.3	--	--	8.1
	5.7	1890	0	1550	60	.4	64	31	1.4	.0	.01	9.0
15	7.7	690	0	570	28	--	2800	22	.4	--	--	15
16	3.9	330	0	272	11	--	270	4.0	.6	--	--	8.3
17	7.8	660	0	554	17	--	2300	13	1.9	--	--	14
18	6.8	596	0	489	30	--	2800	17	.2	--	--	12
	7.4	650	0	530	52	.5	3000	16	.4	.1	.01	12
19	22	976	0	800	78	--	6100	38	.4	--	--	15
20	12	1400	0	1150	56	--	1800	40	.6	--	--	14
21	9.6	907	0	744	46	--	3200	33	.4	--	--	14
	--	--	--	--	--	.2	--	--	--	--	--	--
22	8.8	846	0	694	27	--	3700	26	.4	--	--	12
	--	--	--	--	--	.3	--	--	--	--	--	--
	9.3	840	0	690	27	--	3600	26	.3	--	--	15
23	28	493	0	404	50	--	3000	56	.3	--	--	8.2
24	5.3	1610	0	1320	20	--	130	22	2.9	--	--	7.5
25	18	1230	0	1010	16	--	3900	28	1.5	--	--	8.0
	20	--	0	1070	--	.8	3600	28	1.5	.3	.00	7.8
26	4.6	1660	73	1610	7.3	--	.5	16	2.1	--	--	8.4
27	5.4	1880	0	1550	48	--	.0	18	1.8	--	--	8.6
	--	--	--	--	--	1.8	--	--	--	--	--	--
28	1.6	422	0	346	11	--	71	6.7	.6	--	--	16
	1.7	422	0	346	34	--	55	6.0	.6	--	--	13
29	4.2	301	0	247	24	--	270	3.9	.7	--	--	2.1

Table 40.--Chemical, heavy metals, and radiochemical analyses of ground water from the vicinity of the Hanging Woman Creek study area.--continued

IDENTIFICATION NUMBER	TOTAL FILT-RABLE RESIDUE (MG/L)	DIS-SOLVED SOLIDS (SUM OF CONSTI-TUENTS) (MG/L)	TOTAL NON-FILT-RABLE RESIDUE (MG/L)	DIS-SOLVED NITRATE (N) (MG/L)	DIS-SOLVED NITRATE (NO3) (MG/L)	TOTAL NITRITE PLUS NITRATE (N) (MG/L)	DIS-SOLVED NITRITE PLUS NITRATE (N) (MG/L)	TOTAL AMMONIA NITRO-GEN (N) (MG/L)	DIS-SOLVED AMMONIA NITRO-GEN (N) (MG/L)	DIS-SOLVED AMMONIA (NH4) (MG/L)	TOTAL ORGANIC NITRO-GEN (N) (MG/L)	TOTAL KJEL-DAHL NITRO-GEN (N) (MG/L)
1	--	1850	--	.00	.00	--	--	--	--	--	--	--
2	--	5660	--	1.5	6.5	--	--	--	--	--	--	--
3	--	483	--	.05	.20	--	--	--	--	--	--	--
4	--	6840	--	1.7	7.5	--	--	--	--	--	--	--
5	--	1370	--	.03	.10	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
6	--	--	--	--	--	--	--	--	--	--	--	--
	--	2600	--	<.02	--	--	--	--	--	--	--	--
7	--	1570	--	1.9	8.6	--	--	--	--	--	--	--
8	--	4900	--	<.02	--	--	--	--	--	--	--	--
	--	4980	--	--	--	.09	.01	--	2.4	3.1	--	2.4
9	--	2950	--	<.02	--	--	--	--	--	--	--	--
	--	3000	--	--	--	.01	.01	--	2.0	2.6	--	1.9
10	--	1280	--	--	--	--	--	--	--	--	--	--
	--	1270	--	--	--	.97	--	2.5	--	--	.30	2.8
11	--	5910	--	--	--	--	--	--	--	--	--	--
12	1600	1610	--	--	--	.05	.05	--	2.9	3.7	--	2.7
	--	1610	--	.03	.10	--	--	--	--	--	--	--
13	--	1420	--	.04	.20	--	--	--	--	--	--	--
	1500	1430	1	--	--	.02	.01	--	2.8	3.6	--	3.0
14	--	1730	--	.16	.70	--	--	--	--	--	--	--
	1800	1800	--	--	--	.02	.02	--	3.3	4.3	--	3.2
15	--	4560	--	12	53	--	--	--	--	--	--	--
16	--	638	--	.68	3.0	--	--	--	--	--	--	--
17	--	3760	--	2.5	11	--	--	--	--	--	--	--
18	--	4660	--	1.9	8.5	--	--	--	--	--	--	--
	--	4610	--	--	--	5.0	3.2	--	.00	.00	.00	.85
19	--	9460	--	<.02	--	--	--	--	--	--	--	--
20	--	3800	--	.18	.80	--	--	--	--	--	--	--
21	--	5210	--	<.02	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
22	--	5880	--	.05	.20	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
	--	5750	--	.03	.10	--	--	--	--	--	--	--
23	--	4650	--	.18	.80	--	--	--	--	--	--	--
24	1800	1610	250	--	--	.02	--	2.1	--	--	.30	2.4
25	7300	6650	140	--	--	.00	--	7.0	--	--	.30	7.3
	3400	6360	36	--	--	.01	--	3.8	--	--	2.4	--
26	--	1600	--	.09	.40	--	--	--	--	--	--	--
27	--	1670	--	.07	.30	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
28	--	461	--	1.7	7.4	--	--	--	--	--	--	--
	--	438	--	1.8	7.8	--	--	--	--	--	--	--
29	--	760	--	.68	3.0	--	--	--	--	--	--	--

Table 40.--Chemical, heavy metals, and radiochemical analyses of ground water from the vicinity of the Hanging Woman Creek study area.--continued

IDENTIFICATION NUMBER	DIS-SOLVED CADMIUM (CD) (UG/L)	DIS-SOLVED CHROMIUM (CR) (UG/L)	DIS-SOLVED COPPER (CU) (UG/L)	DIS-SOLVED GALLIUM (GA) (UG/L)	DIS-SOLVED GERMANIUM (GE) (UG/L)	DIS-SOLVED IRON (FE) (UG/L)	DIS-SOLVED LEAD (PB) (UG/L)	DIS-SOLVED LITHIUM (LI) (UG/L)	DIS-SOLVED MANGANESE (MN) (UG/L)	DIS-SOLVED MERCURY (HG) (UG/L)	DIS-SOLVED MOLYBDENUM (MO) (UG/L)	DIS-SOLVED NICKEL (NI) (UG/L)
1	--	--	--	--	--	10	--	--	10	--	--	--
2	--	--	--	--	--	50	--	--	280	--	--	--
3	--	--	--	--	--	20	--	--	50	--	--	--
4	--	--	--	--	--	90	--	--	1510	--	--	--
5	<10	<10	10	--	--	80	<10	90	0	<.3	<20	30
	--	--	--	--	--	--	--	--	--	--	--	--
6	--	--	--	--	--	--	--	--	--	--	--	--
	10	<10	40	--	--	710	<10	150	30	--	--	--
7	--	--	--	--	--	0	--	--	0	--	--	--
8	<10	20	10	--	--	30	200	250	250	--	<20	50
	0	0	0	--	--	1400	0	250	370	.0	0	--
9	10	<10	10	--	--	20	<10	230	20	--	<20	30
	0	0	0	--	--	150	2	220	30	.0	0	--
10	--	--	--	--	--	50	--	--	0	--	--	--
	--	--	2	--	--	230	--	--	--	.2	--	--
11	--	--	--	--	--	30	--	--	0	--	--	--
12	0	0	5	--	--	470	4	110	40	.0	0	--
	<10	--	10	--	--	100	<10	--	50	--	<20	--
13	<10	<10	<10	--	--	80	10	90	10	--	<20	--
	0	0	0	--	--	110	0	100	0	.0	0	--
14	<10	<10	<10	--	--	<10	<10	110	10	--	<20	20
	0	0	0	--	--	40	2	120	10	.0	0	--
15	10	<10	10	--	--	60	120	240	400	--	<20	60
16	--	--	--	--	--	20	--	--	0	--	--	--
17	10	<10	10	--	--	110	80	200	180	--	<20	80
18	--	--	--	--	--	0	--	--	10	--	--	--
	0	0	0	--	--	220	2	210	30	.0	0	--
19	10	10	30	--	--	390	160	500	60	--	<20	120
20	10	<10	10	--	--	30	<10	280	20	--	<20	40
21	20	10	30	--	--	70	<10	260	610	<.3	<20	90
	--	--	--	--	--	--	--	--	--	--	--	--
22	20	20	20	--	--	190	<10	270	1200	<.3	<20	100
	--	--	--	--	--	--	--	--	--	--	--	--
	10	10	10	--	--	50	80	290	640	--	<20	80
23	--	--	--	--	--	0	--	--	0	--	--	--
24	0	<12	<3	<6	<18	50	<12	150	<12	.0	20	<12
25	0	<40	<10	<20	<60	210	<40	420	40	.0	90	<40
	0	<100	10	<40	<150	940	<100	360	80	<.5	<50	<100
26	--	--	--	--	--	0	--	--	0	--	--	--
27	10	<10	10	--	--	110	<10	140	30	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
28	--	--	--	--	--	20	--	--	0	--	--	--
	--	--	--	--	--	0	--	--	0	--	--	--
29	--	--	--	--	--	0	--	--	0	--	--	--

Table 40.--Chemical, heavy metals, and radiochemical analyses of ground water from the vicinity of the Hanging Woman Creek study area.--continued

IDENTIFICATION NUMBER	TOTAL NITRO-GEN (N) (MG/L)	TOTAL NITRO-GEN (NO3) (MG/L)	TOTAL PHOS-PHORUS (P) (MG/L)	TOTAL PHOS-PHORUS (PO4) (MG/L)	DIS-SOL-VED-PHOS-PHORUS (P) (MG/L)	DIS-SOLVED ALUM-INUM (AL) (UG/L)	DIS-SOLVED ANTI-MONY (SB) (UG/L)	DIS-SOLVED ARSENIC (AS) (UG/L)	DIS-SOLVED BARIUM (BA) (UG/L)	DIS-SOLVED BERYL-LIUM (BE) (UG/L)	DIS-SOLVED BISMUTH (BI) (UG/L)	DIS-SOLVED BORON (B) (UG/L)
1	--	--	--	--	--	--	--	--	--	--	--	--
2	--	--	--	--	--	--	--	--	--	--	--	--
3	--	--	--	--	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	--	--	--	--	--	--
5	--	--	--	--	.16	50	<200	<2	--	<5	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
6	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	.09	510	--	<2	--	--	--	--
7	--	--	--	--	--	--	--	--	--	--	--	--
8	--	--	--	--	.13	100	200	<2	--	<5	--	--
	2.5	11	.01	.03	--	50	--	1	0	--	--	80
9	--	--	--	--	.15	140	<200	<2	--	<5	--	--
	1.9	8.5	.06	.18	--	0	--	0	0	--	--	100
10	--	--	--	--	--	--	--	--	--	--	--	--
	3.8	17	.10	--	--	--	--	1	--	--	--	80
11	--	--	--	--	--	--	--	--	--	--	--	--
12	2.8	12	.05	.15	--	0	--	0	300	--	--	110
	--	--	--	--	.07	--	<200	<2	--	<5	--	--
13	--	--	--	--	88	80	20	<2	--	<5	--	--
	3.0	13	.13	.40	--	0	--	0	400	--	--	110
14	--	--	--	--	.02	120	<200	<2	--	<5	--	--
	3.2	14	.09	.28	--	0	--	0	300	--	--	90
15	--	--	--	--	.13	<50	210	<2	--	<5	--	--
16	--	--	--	--	--	--	--	--	--	--	--	--
17	--	--	--	--	.14	<50	230	<2	--	<5	--	--
18	--	--	--	--	--	--	--	--	--	--	--	--
	5.9	26	--	.00	--	30	--	0	0	--	--	130
19	--	--	--	--	.04	<50	310	<2	--	<5	--	--
20	--	--	--	--	.07	<50	<200	<2	--	<5	--	--
21	--	--	--	--	.03	70	430	<2	--	<5	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
22	--	--	--	--	.17	<50	450	<2	--	<5	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	.25	70	290	<2	--	<5	--	--
23	--	--	--	--	--	--	--	--	--	--	--	--
24	2.4	11	.20	--	--	40	--	1	80	<3	<18	<12
25	7.3	32	.07	--	--	100	--	1	77	<10	<60	<40
	6.2	28	.04	--	--	120	--	0	70	<30	<100	<100
26	--	--	--	--	--	--	--	--	--	--	--	--
27	--	--	--	--	.07	70	--	<2	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
28	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
29	--	--	--	--	--	--	--	--	--	--	--	--

Table 40.--Chemical, heavy metals, and radiochemical analyses of ground water from the vicinity of the Hanging Woman Creek study area.--continued

IDENTIFICATION NUMBER	DIS-SOLVED SELE-NIUM (SE) (UG/L)	DIS-SOLVED SILVER (AG) (UG/L)	DIS-SOLVED STRON-TIUM (SR) (UG/L)	DIS-SOLVED TIN (SN) (UG/L)	DIS-SOLVED TI-TANIUM (TI) (UG/L)	DIS-SOLVED VANA-DIUM (V) (UG/L)	DIS-SOLVED ZINC (ZN) (UG/L)	DIS-SOLVED ZIR-CONIUM (ZR) (UG/L)	DIS-SOLVED GROSS ALPHA AS U-NAT. (UG/L)	SUS-PENDED GROSS ALPHA AS U-NAT. (UG/L)	DIS-SOLVED GROSS BETA AS CS-137 (PC/L)	SUS-PENDED GROSS BETA AS CS-137 (PC/L)
1	--	--	--	--	--	--	--	--	--	--	--	--
2	--	--	--	--	--	--	--	--	--	--	--	--
3	--	--	--	--	--	--	--	--	--	--	--	--
4	--	--	--	--	--	--	--	--	--	--	--	--
5	<2	<10	390	40	--	--	30	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
6	--	--	--	--	--	--	--	--	--	--	--	--
	0	--	690	--	--	--	--	--	--	--	--	--
7	--	--	--	--	--	--	--	--	--	--	--	--
8	<2	<10	5300	520	--	--	50	--	--	--	--	--
	0	--	4800	--	--	.1	40	--	--	--	--	--
9	<2	<10	3070	410	--	--	40	--	--	--	--	--
	0	--	2900	130	--	.2	60	--	--	--	--	--
10	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
11	--	--	--	--	--	--	--	--	--	--	--	--
12	0	--	370	--	--	1.2	390	--	--	--	--	--
	<2	<10	400	120	--	--	490	--	--	--	--	--
13	<2	<10	280	--	--	--	10	--	--	--	--	--
	0	--	280	--	--	.5	10	--	<17	<.4	<7.3	<.4
14	<2	<10	420	150	--	--	50	--	--	--	--	--
	0	--	410	--	--	1.6	10	--	--	--	--	--
15	17	<10	4800	1100	--	--	20	--	--	--	--	--
16	--	--	--	--	--	--	--	--	--	--	--	--
17	<2	<10	4600	910	--	--	60	--	--	--	--	--
18	--	--	--	--	--	--	--	--	--	--	--	--
	1	--	3300	--	--	.2	350	--	--	--	--	--
19	2	10	11000	1800	--	--	230	--	--	--	--	--
20	<2	<10	5600	530	--	--	140	--	--	--	--	--
21	<2	10	5200	770	--	--	110	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
22	<2	10	5000	910	--	--	80	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
	<2	--	4800	1500	--	--	40	--	--	--	--	--
23	--	--	--	--	--	--	--	--	--	--	--	--
24	--	<2	470	<18	<6	<12	310	<18	<20	27	<7.0	10
25	--	<4	3900	<60	<20	<40	10	<60	<83	8.9	<23	6.1
	0	<10	4400	<100	<80	<75	30	<150	<52	1.6	<18	1.8
26	--	--	--	--	--	--	--	--	--	--	--	--
27	<2	--	410	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
28	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
29	--	--	--	--	--	--	--	--	--	--	--	--

Table 40.--Chemical, heavy metals, and radiochemical analyses of ground water from the vicinity of the Hanging Woman Creek study area.--continued

IDENTIFICATION NUMBER	DIS-SOLVED GROSS BETA AS SR90 /Y90 (PC/L)	SUS-PENDED GROSS BETA AS SR90 /Y90 (PC/L)	TOTAL ORGANIC CARBON (C) (MG/L)	DIS-SOL-VED ORGANIC CARBON (C) (MG/L)
1	--	--	--	--
2	--	--	--	--
3	--	--	--	--
4	--	--	--	--
5	--	--	--	--
	--	--	--	--
6	--	--	--	--
	--	--	--	--
7	--	--	--	--
8	--	--	--	--
	--	--	--	6.6
9	--	--	--	--
	--	--	--	5.9
10	--	--	--	--
	--	--	--	--
11	--	--	--	--
12	--	--	--	11
	--	--	--	--
13	--	--	--	--
	<5.8	<.4	--	6.2
14	--	--	--	--
	--	--	--	5.0
15	--	--	--	--
16	--	--	--	--
17	--	--	--	--
18	--	--	--	--
	--	--	--	4.0
19	--	--	--	--
20	--	--	--	--
21	--	--	--	--
	--	--	--	--
22	--	--	--	--
	--	--	--	--
	--	--	--	--
23	--	--	--	--
24	<5.6	8.8	--	--
25	<19	4.8	--	--
	<14	1.5	6.7	--
26	--	--	--	--
27	--	--	--	--
	--	--	--	--
28	--	--	--	--
	--	--	--	--
29	--	--	--	--

All but three concentrations of dissolved solids, most concentrations of dissolved sulfate, and several concentrations for iron and manganese for water samples collected from wells in the East Trail Creek area are greater than the recommended maximum concentrations. The only abnormally high concentration observed for a minor element was for strontium. The highest concentration was 11,000 μg/l (micrograms per liter) in well 09S44E07BBCC1 which taps the Anderson coal. Wells tapping other aquifers also contain high strontium, but no deleterious effects are known to be caused by this element. The dissolved-solids concentrations in all samples are below limits for drinking by beef cattle (McKee and Wolfe, 1963).

The analyses of water from the Hanging Woman Creek study area can be separated into three distinct groups according to dominant-ion concentrations (Figures 43 and 44):

Group I is dominated by Na and HCO_3 ions with dissolved-solids concentrations generally ranging from about 1,200 to 3,000 mg/l. Group I analyses generally describe the chemical quality of water in the reducing environment of coal aquifers.

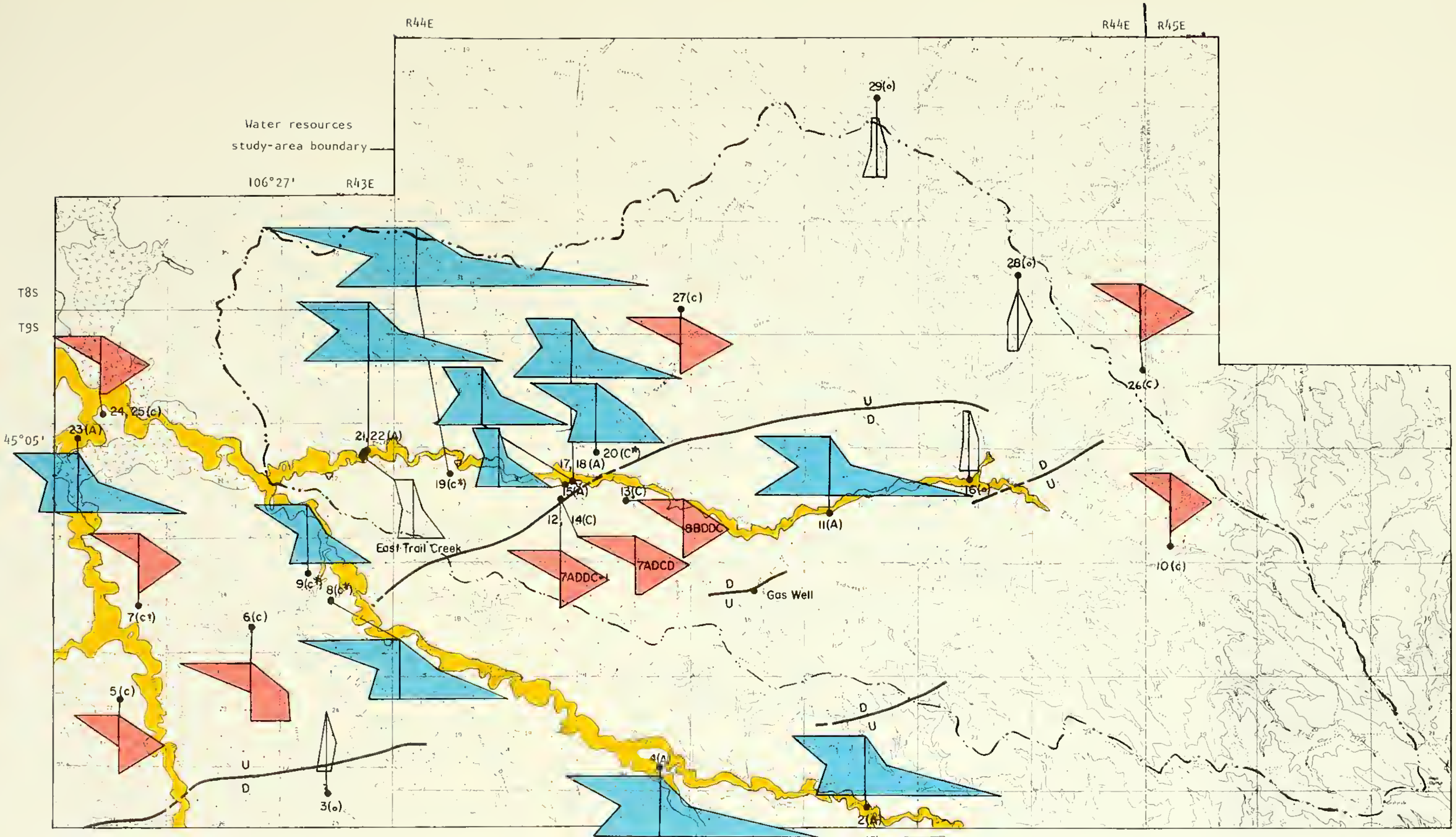
Group II is dominated by Na, Mg, and SO_4 ions with dissolved-solids concentrations generally greater than 2,500 mg/l. Group II analyses generally describe the chemical quality of water in the oxidizing environment of alluvium, units within the shallow Tongue River Member, or coal beds immediately subjacent to alluvium, or eroded and filled by alluvium. Analyses of water from East Trail Creek (Table 37) also are included in this group.

Group III is dominated by Ca, Mg, HCO_3 and SO_4 ions with dissolved-solids concentrations less than about 800 mg/l. Group III analyses come from four sample locations that do not readily correlate areally or vertically with other analyses or geology.

The variability of ground-water quality can be attributed to the abundance and composition of soluble minerals in aquifers and percolation zones, the flow path taken by the water, the amount of time water resides in the ground, the chemical reactions that take place, and the amount of mixing between waters in different aquifers. Specifically, water in coal aquifers that initially percolate through overlying material probably changed chemically from Group II to Group I water. A simple reaction creating this change could be sulfate reduction as the water migrated from the oxidizing environment of the alluvium to the reducing environment of the coal:

$$SO_4^{-2} + \underbrace{2C \cdot H_2O}_{\text{coal}} \longrightarrow 2HCO_3^{-} + H_2S$$

Although the process almost certainly occurs in coal beds, alkalinity does not increase in proportion to the reduction in sulfate. Therefore,



Base from U.S. Geological Survey, state base map, 1968.

from Culbertson and Klett (unpublished mapping)

EXPLANATION

Datum is mean sea level.

HOLOCENE

Qal ALLUVIUM - Mostly floodplain deposits of silt, clay, and fine gravel; and colluvium. Maximum thickness 40 feet.

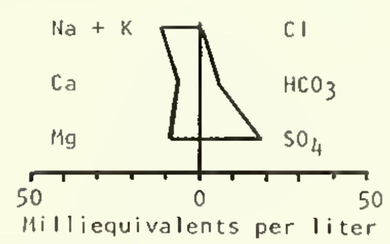
CLINKER - Baked sandstone, siltstone and shale of Fort Union Formation produced by the burning of Anderson coal bed. Maximum thickness 50 ft.

EOCENE AND PALEOCENE

WASATCH FORMATION AND TONGUE RIVER MEMBER OF THE FORT UNION FORMATION sandstone, siltstone, shale, and coal.

Geologic contact. Dashed where concealed.

Fault. U, upthrown side; D, downthrown side; dashed where concealed.



Drainage boundary for East Trail Creek.

Stream-gaging and water-quality station.

Low-flow streamflow station (flume).

19(c*) Well--circle indicates chemical analysis of water. Number is identification from tables 40 - 41. Letter is geologic source: A, alluvium or shallow non-coal unit of Tongue River Member; C, coal; C*, coal in contact or near contact with alluvium; O, composite.

Group I - reducing environment of coal aquifer.

Group II - Oxidizing environment of alluvium, units within shallow Tongue River Member, or coalbeds subjacent to alluvium.

Group III - Analysis not correlated with geology.

Figure 43. MAP SHOWING GEOLOGY, MEASUREMENT SITES, AND GROUND-WATER QUALITY

EXPLANATION

• 28 — Water analyses from alluvium and Tongue River Member
Number is identification from tables 40 & 41

T — Indicates analyses which appear to be transitional between oxidizing environment of alluvium and reducing environment of coal

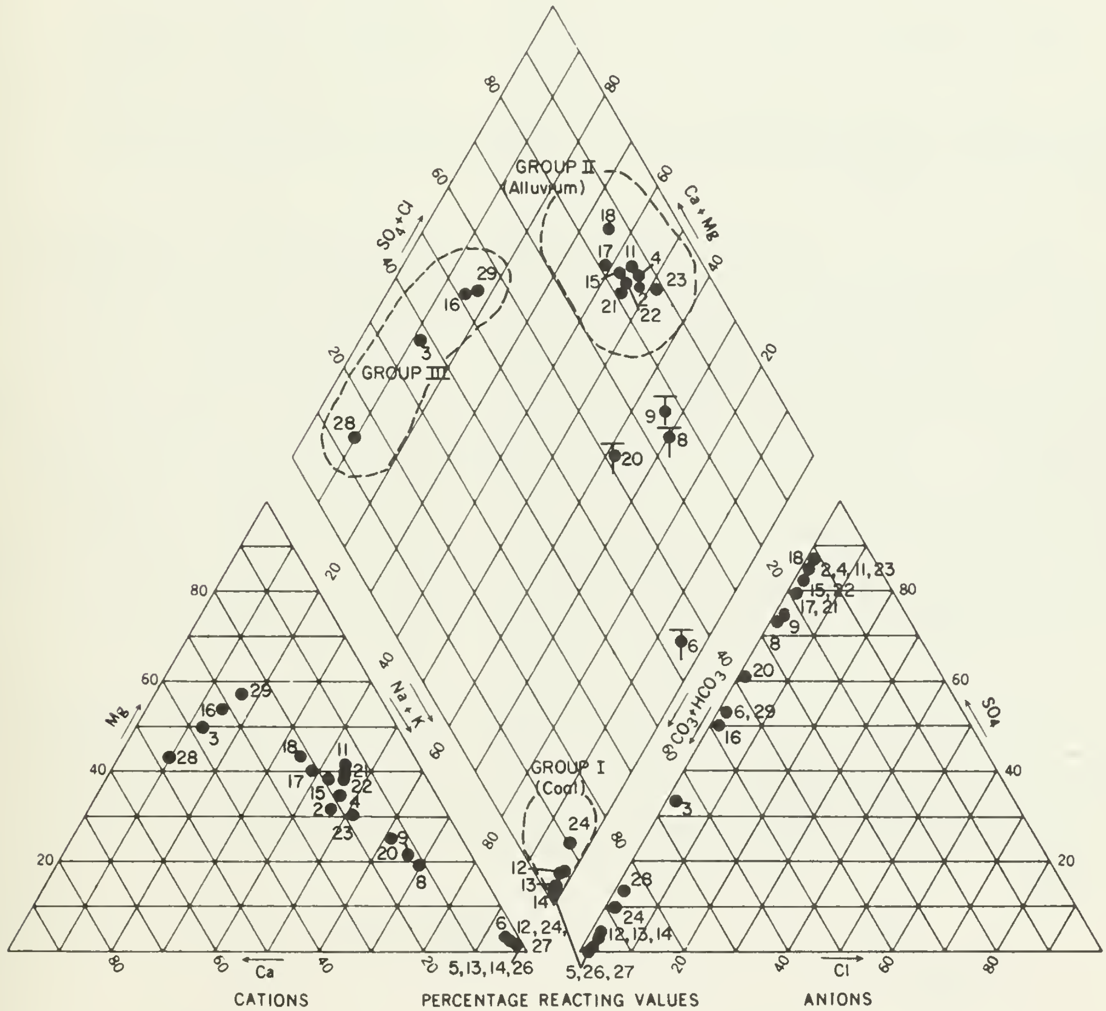


Figure 44. Water-analysis diagram of ground water.

this process alone cannot explain the observed alteration. In addition, the changes in dominant ions together with a general decrease in dissolved-solids concentration suggest more complicated processes.

Another sulfate-reducing reaction requires the presence of anaerobic bacteria as a catalyst:

$$SO_4^{-2} + CH_4 \xrightarrow[\text{bacteria}]{\text{anaerobic}} H_2S + HCO_3^- + OH^-$$

A sulfate-reducing reaction that may occur in the presence of ferrous iron is:

$$2Fe^{+2} + 4SO_4^{-2} + 2H_2O + 7C \longrightarrow 2FeS_2 + 4HCO_3^- + 3CO_2$$

Cation exchange in clay surfaces along the ground-water flow path also may occur in this chemical process, as in the replacement of calcium and magnesium by sodium.

The variability of ground-water quality might also be attributed to juxtaposition of coal beds and alluvium across the East Trail Creek fault, which may be analagous to the coal-spoil interface at the edge of the strip mine. Some wells tapping a coal bed upstream and downstream from the fault contain water in Group I and Group II, respectively. The difference in water classification could be the result of elevation of the Anderson coal bed on the downstream side of the fault into an oxidizing environment. Analyses 6, 8, 9, and 20 (Tables 40 and 41, and Figure 44) from wells tapping the Anderson coal far removed from the alluvium show cation and anion distribution that appears to be transitional between Groups I and II. These analyses possibly represent the condition of shallow water being introduced into the coal on the upthrown block of the fault. If so, the hypothetical chemical processes may be in a transient state.

Well 09S44E16ACCB was drilled 183 feet (56 m) into the Anderson coal bed on the upthrown (south) block of a small fault (Figure 43) having a displacement of about 110 feet (3.35 m). This well produces gas under a constant pressure of about 18 lb/in^2 (1266 g/cm^2). The gas composition was analyzed as 96.7% methane and 2.7% nitrogen with traces of carbon dioxide and ethane. Methane gas can be produced in coal by oxidation of the coal:

$$\underbrace{2C \cdot 2H_2O}_{\text{coal}} \longrightarrow CO_2 + CH_4$$

or

$$\text{Coal} \longrightarrow \text{Coal (oxidized)} + CH_4$$

In either reaction, methane gas is produced and may be available for processes discussed earlier or as free gas structurally trapped by the

Table 41.--Percentage reacting values used in the water-analysis diagram (Figure 44).

IDENTIFICATION NUMBER[a]		SAMPLE IDENTIFICATION DATE/Y/M/D TIME	NA+K	CA+MG	CA	MG	PERCENTAGES HCO3+ CO3	CL+SO4 +NO3	CL	SO4	NO3	BALANCE
2.	09S44E27ABCB	STOCK WELL (COMPOSITE) 057 1975 6 4 1700	40.86	53.14	21.66	31.28	14.12	85.68	0.45	85.41	-1.00	1.01
3.	09S43E25BADC	STOCK SPR. 057 1974 2 28 1650	13.84	86.16	36.44	49.73	62.81	37.19	1.57	35.49	-1.00	1.00
4.	09S44E20DCAA	STOCK WELL (DIETZ & SNDSTONE) 057 1975 6 4 1600	46.70	53.30	18.06	35.24	13.15	86.85	0.77	86.06	-1.00	1.01
5.	09S43E22ACCA	HWC-15 (ANDERSON) 057 1977 6 23 1210	97.81	2.19	1.04	1.15	98.25	1.75	1.72	0.02	-1.00	1.05
6.	09S43E14DBBB	HWC-27 (ANDERSON) 057 1977 7 8 1400	95.31	4.69	2.30	2.39	44.60	55.40	1.20	54.10	-1.00	1.03
8.	09S43E13CAAA	2 HWC-07 (ANDERSON) 057 1977 4 29 1000	70.05	29.95	11.31	18.64	25.16	74.64	1.72	73.09	-1.00	1.03
	09S43E13CAAA	2 HWC-07 (ANDERSON) 057 1977 4 29 1200	70.06	29.94	11.31	18.64	24.76	75.24	0.61	74.59	-1.00	1.04
9.	09S43E13BDBB	HWC-17 (ANDERSON) 057 1977 4 19 1000	68.07	31.93	10.65	21.28	25.20	74.80	1.00	73.75	-1.00	0.97
	09S43E13BDBB	HWC-17 (ANDERSON) 057 1977 4 27 1730	66.68	33.32	11.91	21.41	23.49	76.51	0.78	75.64	-1.00	1.02
10.	09S45E07CCAD	STOCK WELL (COMPOSITE) 057 1974 2 2 1450	96.65	3.35	2.04	1.30	98.15	1.85	1.78	0.07	-1.00	0.99
11.	09S44E10CBAD	STOCK WELL (ALLUVIUM) 057 1975 6 4 1830	43.68	56.32	14.79	41.53	12.85	87.15	0.56	86.58	-1.00	1.00
12.	09S44E07ADDC	1 HWC-08 (DIETZ) 057 1977 4 28 940	96.91	3.09	1.58	1.52	94.63	5.37	2.36	3.00	-1.00	1.00
	09S44E07ADDC	1 HWC-08 (DIETZ) 057 1977 4 26 1000	96.98	3.02	1.48	1.54	94.47	5.53	2.42	3.10	-1.00	1.03
13.	09S44E08BDDC	HWC-18 (ANDERSON) 057 1977 4 28 1000	97.46	2.54	1.21	1.33	97.45	2.55	2.52	0.02	-1.00	1.03
	09S44E08BDDC	HWC-18 (ANDERSON) 057 1977 4 28 1630	97.44	2.56	1.28	1.27	96.74	3.26	2.54	0.72	-1.00	1.01
14.	09S44E07ADCD	HWC-20 (ANDERSON) 057 1977 4 26 1200	96.50	3.50	1.81	1.69	93.35	6.65	2.63	4.01	-1.00	1.01
15.	09S44E07ADAC	HWC-34 (ALLUVIUM) 057 1977 9 29 2140	42.71	57.29	19.47	37.82	16.10	83.90	0.86	82.99	-1.00	0.98
16.	09S44E11BDAA	STOCK WELL (COMPOSITE) 057 1975 6 3 1100	14.57	85.43	32.26	53.17	48.54	51.46	1.01	50.31	-1.00	1.00
17.	09S44E07ADAB	HWC-33 (ALLUVIUM) 057 1977 9 13 1000	39.26	60.74	19.85	40.89	18.76	81.24	0.62	80.48	-1.00	0.99
18.	09S44E07ADAA	STOCK WELL (ANDERSON & ALLVM) 057 1974 2 28 1140	40.25	59.75	20.72	39.03	14.25	85.75	0.70	85.04	-1.00	1.02
	09S44E07ADAA	STOCK WELL (ANDERSON & ALLVM) 057 1977 4 28 1130	33.40	66.60	22.52	44.08	14.48	85.52	0.61	84.88	-1.00	1.04
19.	09S44E07BBCC	1 HWC-29 (ANDERSON) 057 1977 9 27 1340	54.60	45.40	16.93	28.47	11.10	88.90	0.74	88.14	-1.00	1.00
20.	09S44E08BBAB	2 HWC-26 (ANDERSON) 057 1977 4 28 1000	61.87	38.13	14.40	23.73	37.28	62.72	1.83	60.86	-1.00	0.99
21.	09S43E12ABDD	1 HWC-35 (ANDERSON & ALLVM) 057 1977 6 21 1300	46.56	53.44	15.68	37.77	18.04	81.96	1.13	80.81	-1.00	1.00
22.	09S43E12ABDD	2 HWC-36 (ALLUVIUM) 057 1977 6 21 1500	43.59	56.41	17.64	38.77	15.13	84.87	0.80	84.05	-1.00	0.98
	09S43E12ABDD	2 HWC-36 (ALLUVIUM) 057 1977 9 20 700	45.89	54.11	16.36	37.75	15.39	84.61	0.82	83.77	-1.00	0.98
23.	09S43E10BBAD	STOCK WELL (COMPOSITE) 057 1974 2 26 1420	50.77	49.23	19.03	30.20	11.20	88.80	2.19	86.59	-1.00	1.02
26.	09S44E01ADAA	STOCK WELL (ANDERSON) 057 1974 2 28 1630	96.71	3.29	1.92	1.37	98.47	1.53	1.49	0.03	-1.00	1.03
27.	08S44E32DDAB	HWC-28 (ANDERSON) 057 1977 7 6 1240	96.68	3.32	1.58	1.74	98.38	1.62	1.62	0.00	-1.00	0.99
28.	08S44E35ADDC	STOCK WELL (COMPOSITE) 057 1974 2 3 1115	10.35	89.65	44.79	44.86	80.58	19.42	2.19	17.16	-1.00	0.98
	08S44E35ADDC	STOCK WELL (COMPOSITE) 057 1975 6 19 1000	9.15	90.85	46.65	44.20	84.03	15.97	2.05	13.66	-1.00	0.97
29.	08S44E22DCDB	STOCK WELL (COMPOSITE) 057 1975 6 19 1000	16.22	83.78	26.20	57.58	46.26	53.74	1.03	52.53	-1.00	0.99

[a] Missing numbers indicate analyses with incomplete determinations or ion imbalance.

fault. The presence of this gas also indicates that care should be taken during drilling and testing of very shallow coal-bearing formations to keep the gas from igniting.

Future Hydrologic Studies

Monitoring of streamflow, ground-water levels, and water quality will be continued to more completely define seasonal fluctuations and the baseline hydrologic system. Continued data collection will also be used to determine basin reaction to severe and unique hydrologic events. Results from the monitoring program will be periodically analyzed to determine the need for continued data collection.

Additional data will be collected on the relationship of flow between East Trail Creek, the alluvium, and coal beds in the vicinity of the East Trail Creek fault. In addition, cross-fault hydraulic and chemical quality experiments might be performed on the water-table aquifer.

Continuing data collection and instrumentation are planned to help calibrate and verify a hydrologic model for the study area. The results of the model effort should refine knowledge of the hydrology and help provide solutions to water problems associated with alternative mining plans. The need for additional data collection must also be determined. Monitoring during and after mining also is necessary to assure optimum reclamation.

Sediment Yields

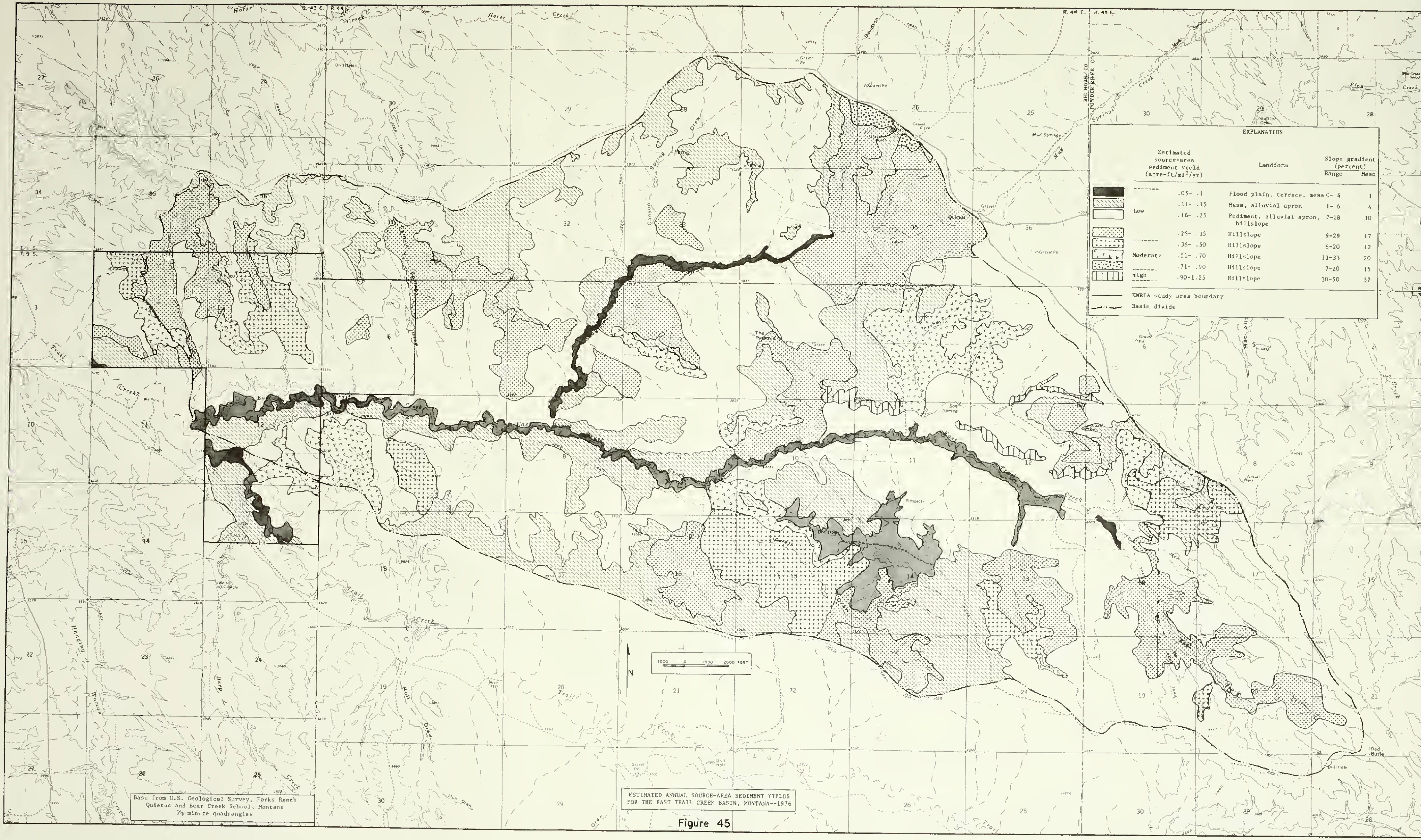
The sediment yield values presented for this area were derived using a numerical rating method developed by the Pacific Southwest Inter-Agency Committee (PSIAC) (1968). They have been judged to be reasonably accurate but they have been only partially verified by field measurements.

The mapping unit that is the basis of this sediment yield evaluation is the source area which is defined as a small drainage area occurring on a single landform type or an inseparable complex of landforms and which is only part of a complete drainage basin. The PSIAC method is used to assess the hydrologic variation of the given landforms as well as to make estimates of sediment yield from them. Numerical ratings are assigned for each of the nine factors of the PSIAC method to representative sediment-source areas in accordance with the degree of influence each factor has on the sediment yield from the area. These nine factors are surface geology, soils, climate, runoff, topography, ground cover, land use, upland erosion and channel erosion, and sediment transport. The method was developed to make broad sediment yield classifications for large areas, such as river subbasins, but Shown (1970) found that the method provides reasonable estimates for small drainage basins (.02 to 7.5 sq mi (.05 to 19 km^2)). In applying the method on source areas, some adjustments are made because a complete drainage system is not being considered. Alluvial fan and flood plain development are not considered in the topography factor and sediment-transport capabilities are not considered for channels that originate in upslope source areas, and that cross through the source area being rated. These factors are taken into account later when making estimates of sediment discharge from drainage basins.

Interpretations of color aerial photographs (1:24,000 scale) were used to extend the source-area sediment-yield estimates to those areas that were not rated during field investigations. This was accomplished with a stereo plotter and resulted in the source-area sediment-yield map shown on Figure 45. The slope data were obtained from the 1:24,000 USGS topographic quadrangles.

The complete main channel system was classified and mapped according to channel type and condition (Figure 46) to aid in assessing channel erosion and deposition. The channel classification was done by interpretation of the aerial photography and only those channels that were larger than third or fourth order according to Stahler's (1952) classification were delineated.

Sediment accumulation was measured in three stock-water ponds in the area by probing from a boat. Sediment-trap efficiency of these ponds was high as water apparently spills from them infrequently. The average annual rate of sediment accumulation in the ponds (see Table 42 on Figure 46) was divided by the area-weighted average source-area sediment yield to obtain estimates of sediment conveyance factors for the channels above the ponds. The sediment conveyance factor represents that part of



Base from U.S. Geological Survey, Forks Ranch Quietus and Bear Creek School, Montana 7½-minute quadrangles

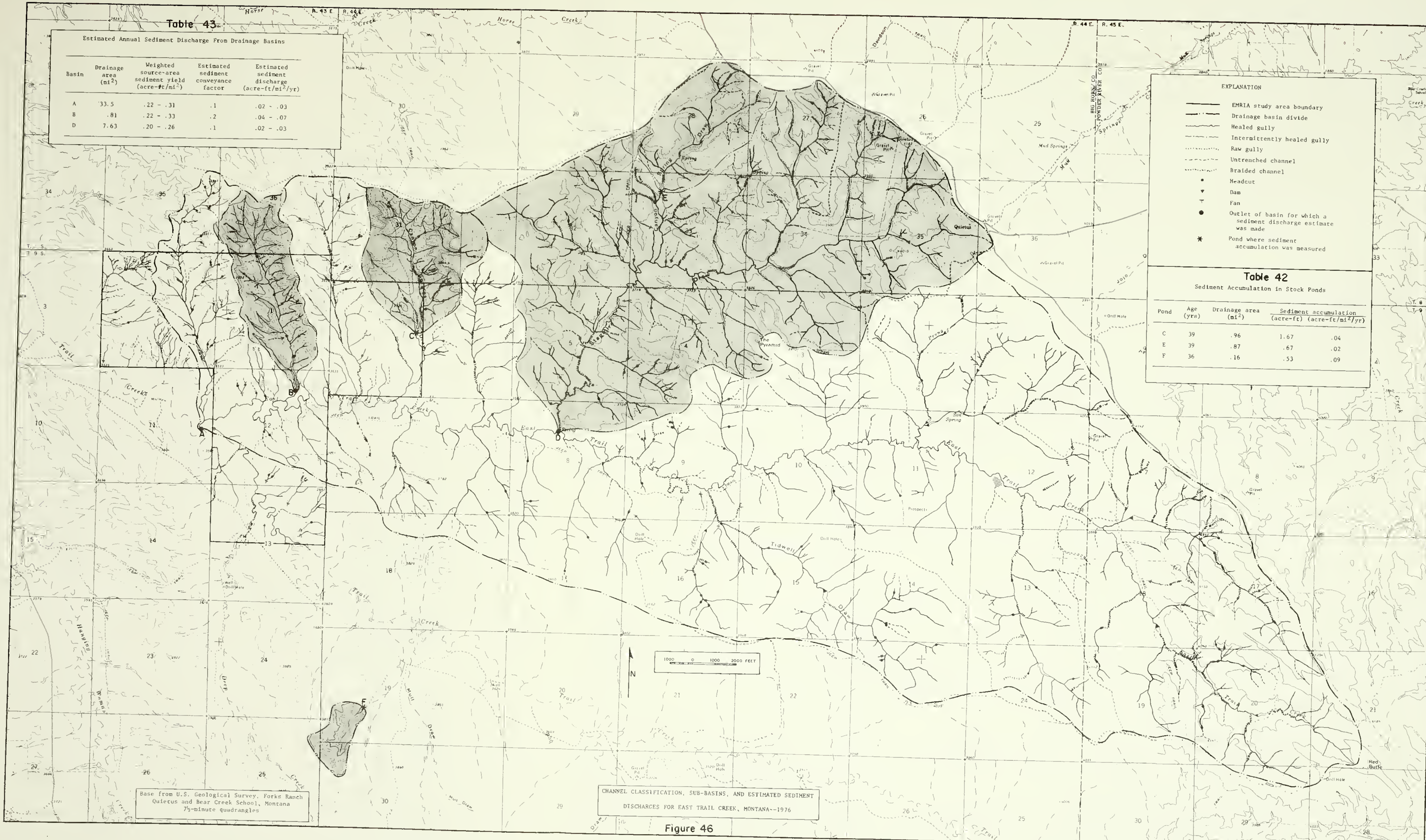
ESTIMATED ANNUAL SOURCE-AREA SEDIMENT YIELDS FOR THE EAST TRAIL CREEK BASIN, MONTANA--1976

Figure 45

Table 43

Estimated Annual Sediment Discharge From Drainage Basins

Basin	Drainage area (mi^2)	Weighted source-area sediment yield (acre-ft/mi^2)	Estimated sediment conveyance factor	Estimated sediment discharge (acre-ft/mi^2/yr)
A	33.5	.22 - .31	.1	.02 - .03
B	.81	.22 - .33	.2	.04 - .07
D	7.63	.20 - .26	.1	.02 - .03



CHANNEL CLASSIFICATION, SUB-BASINS, AND ESTIMATED SEDIMENT DISCHARGES FOR EAST TRAIL CREEK, MONTANA--1976

Figure 46

Table 42

Sediment Accumulation in Stock Ponds

Pond	Age (yrs)	Drainage area (mi^2)	Sediment accumulation (acre-ft)	Sediment accumulation (acre-ft/mi^2/yr)
C	39	.96	1.67	.04
E	39	.87	.67	.02
F	36	.16	.53	.09

the total sediment load entering the main channel and principal tributaries that is transported on through the channel system and not deposited somewhere enroute. The computed sediment-conveyance factors were used as guides when applying the channel classification information on Figure 46 to obtain estimates of the sediment-conveyance factors for subbasins for which estimates of annual sediment discharges were made (see Table 43 on Figure 46). The method used in assigning sediment-conveyance factors was the one reported by Frickel, Shown, and Patton (1975).

Source-Area Sediment Yields

Estimates of source-area sediment yields as shown on Figure 45, while variable, are generally low in the East Trail Creek basin. Yields are lowest from well-grassed bottomlands and from nearly flat, grassy mesas. Yields are low to moderate from gently sloping pediments and from alluvial aprons along valley sides. Highest yields occur from relatively barren, dissected hillslopes. Areas mapped as categories 0.36 to 0.50, 0.51 to 0.70, and 0.71 to 0.90 acre-ft/mi^2 on Figure 45, are, in general, not extremely steep, but produce moderate to high sediment yields because they are well dissected.

Sediment from channel erosion is included in the source area sediment-yield estimates but channel erosion is not a serious problem in the area as channels are widening and deepening in only a few places, and then at slow rates. Most raw gullies, which comprise about 9% of the total channel length of the East Trail Creek basin, have stable banks even though the gully bottoms are barren. There are a number of headcuts in channels throughout the basin, but most of them appear to progress at rates that average less than 10 ft/yr (3 m/yr).

In a few places in the basin, it was observed that cow trails on slopes had intercepted overland flows causing rills or small gullies to form.

Sediment Discharge from Drainage Basins

Low annual rates of sediment accumulation were measured in three stock ponds as shown in the table below the explanation (Table 42, Figure 46). Correspondingly low mean annual sediment discharges were estimated for East Trail Creek near its mouth and at the mouths of two of its tributaries (Table 43, Figure 46). A couple of other factors besides the source-area sediment yields being low cause the sediment discharges to be low. At a maximum, only about one-fourth of the sediment which enters the main channels and principal tributaries is discharged at the mouths of small basins less than 1 sq mi (2.5 km^2) in size. This is based on comparison of the source-area sediment yields and sediment discharges to the ponds of the three basins where sediment accumulations were measured. In those basins, only 11 to 26% of the sediment entering the main channels and principal tributaries reached the ponds. Apparently, much of the sediment entering the channels is deposited on channel beds and flood plains, nearly all of which are well vegetated. About 80% of the channel length in the

East Trail Creek basin and in tributary basins was classified as healed gullies with vegetated beds and about 10% of the length was well-vegetated untrenched channels. These channel conditions apparently cause most of the sediment to deposit from commonly occurring low and moderate flows. Another factor which causes the sediment discharge to be low from East Trail Creek and the largest tributary, Stagmire Draw (Basin D, Figure 46), is that more than one-half of their drainage areas lie above stock ponds which trap much of the sediment coming from headwater areas. All of these factors result in low sediment conveyance by the channels.

Comparison with Bear Creek EMRIA Study Area

Source-area sediment yields in the East Trail Creek basin are similar to those estimated previously for the Bear Creek EMRIA study area (USDI, 1977b) which lies directly east of the upper end of East Trail Creek. The sediment yields are similar even though some controlling factors are different between the two watersheds. Average watershed slope and channel gradients are somewhat steeper and vegetation cover is not quite as dense in the East Trail Creek basin. Those factors are offset by the fact that thicker sandstone outcrops occur in the upper part of the geologic section exposed in the East Trail Creek basin. The resulting greater proportion of sandier soils causes the runoff and erosion to be less.

Sediment discharges from small (0-2 to 5.0 sq mi (0-5 to 13 km^2)) subbasins in the Bear Creek area are greater because a larger proportion of the sediment loads is composed of clay particles which are more readily transported through the channels than are sand particles, which make up a larger proportion of the sediment loads in East Trail Creek.

VEGETATION

For the relatively low annual precipitation, about 15-20 inches (38 to 51 cm), the area has surprisingly diverse vegetation. Geologic, edaphic, and topographic factors contribute to this diversity. Geologic materials include sandstone, silty sandstone, clay, silty shales, and coal beds. Soils range from sandy to clayey and deep to shallow and slopes from flat to steep. In response to these factors, such diverse vegetation types as non-salt-tolerant, non-drought-tolerant ponderosa pine savannah and drought and salt-tolerant shadscale occur within a few tenths of a mile. Species typical of montane habitats to the west, of the Great Plains to the east, and of salt-desert-shrub areas to the southwest of the study area are present.

Aerial cover of vegetation and soil-surface conditions (bare soil, rock, and mulch) were measured by the first-contact point-quadrat method. A frame containing 10 pins was placed along a tape for pin-projection readings. From 300 to 600 readings were made in each type. Current growth of vegetation and mulch weights were made in 2 to 4 plots of 9.6 sq ft (.9 m^2) at each sampling site. Plant materials were oven-dried and are reported as pounds per acre (Table 44). Estimated carrying capacities are based on these yields with adjustments made for such factors as distance from water, slope, and palatability of species. These "ball park" estimates are for cattle; different evaluations of the data would be required for other classes of livestock and game species. Range condition estimates were based on principles proposed by Dyksterhuis (1949).

The high, flat tablelands that form some of the drainage divides have sandy to loamy soils that have developed from a sandstone capping material. These ancient soils have stands characterized by needle-and-thread and big sagebrush (Figure 47, Site 5, Table 44). Other abundant species present were western wheatgrass and blue grama. This site had the lowest productivity and the range condition was 66% which would be classed as good (poor = 0 to 25%, fair = 25 to 50%, good = 50 to 75%, and excellent = 75 to 100% of climax vegetation).

The ponderosa pine-bluebunch wheatgrass typically occurs just below the perimeter of the tablelands. Coarse-textured soils of this site have developed in colluvium formed as the tablelands have been reduced in extent by geologic erosion. Although of about medium productivity for the sites sampled, this site had the highest range condition (91% or high excellent). Species present here that are common in more moist portions of the eastern Great Plains were little bluestem and sideoats grama. This favorable site for plant growth had numerous species present.

A type not mapped separately but present in shallow alluvium of minor tributaries is western wheatgrass-Sandberg bluegrass (Site 8, Table 44). Accessability of this type to domestic animals has caused some reduction in productivity and range condition (68% or good condition).

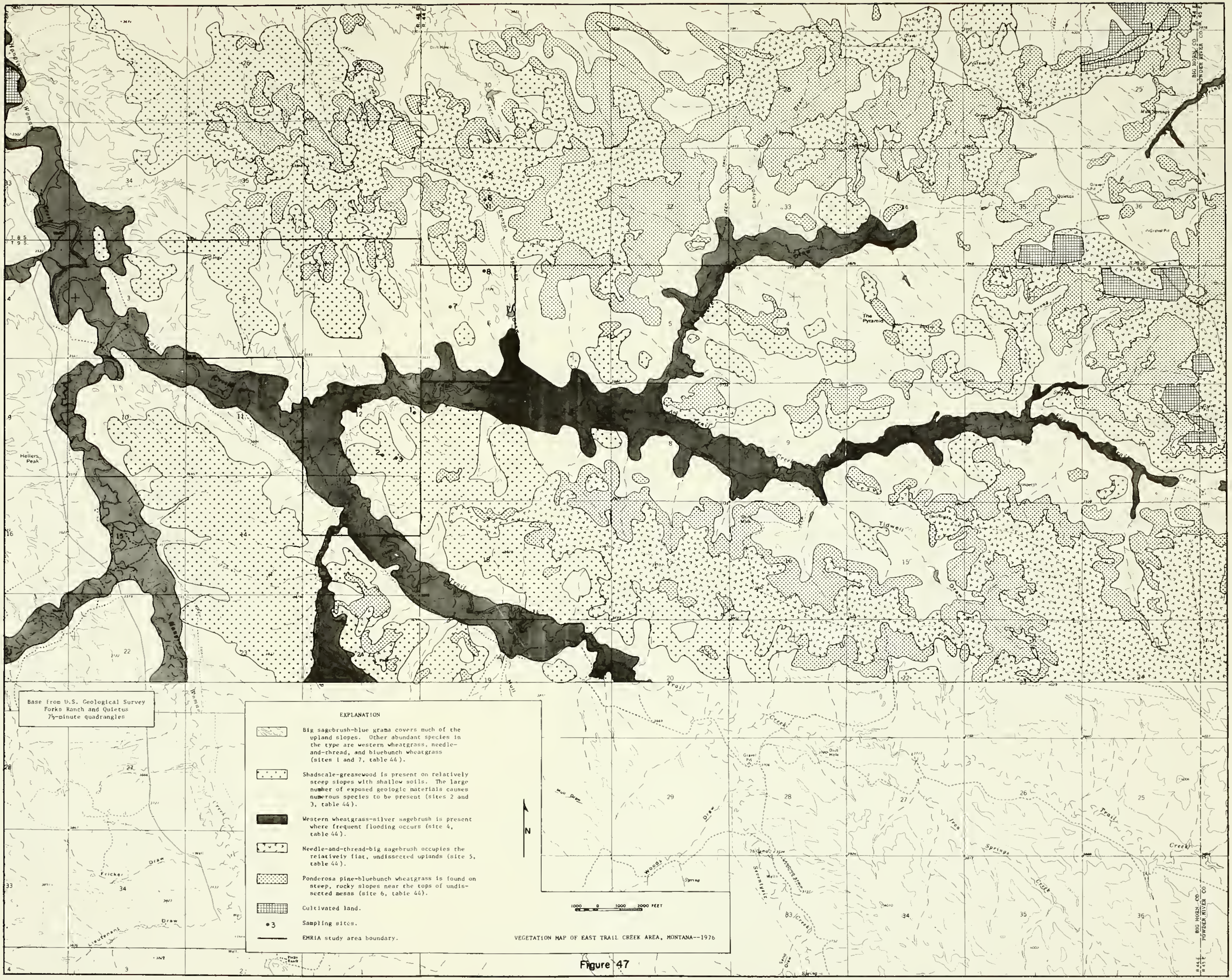

Base from U.S. Geological Survey
Forks Ranch and Quietus
7½-minute quadrangles
EXPLANATION
Big sagebrush-blue grama covers much of the upland slopes. Other abundant species in the type are western wheatgrass, needle-and-thread, and bluebunch wheatgrass (sites 1 and 7, table 44).
Shadscale-greasewood is present on relatively steep slopes with shallow soils. The large number of exposed geologic materials causes numerous species to be present (sites 2 and 3, table 44).
Western wheatgrass-silver sagebrush is present where frequent flooding occurs (site 4, table 44).
Needle-and-thread-big sagebrush occupies the relatively flat, undissected uplands (site 5, table 44).
Ponderosa pine-bluebunch wheatgrass is found on steep, rocky slopes near the tops of undissected mesas (site 6, table 44).
Cultivated land.
•3 Sampling sites.
EMRIA study area boundary.
N
1000 0 1000 2000 FEET
VEGETATION MAP OF EAST TRAIL CREEK AREA, MONTANA--1976
The Pyramid
Tidwell
Hellers Peak
BIG HORN CO.
POWDER RIVER CO.

Figure 47

Table 44.--Percent cover of vegetation, mulch, bare soil and rock plus yields of vegetation and mulch in pounds per acre and range condition in percent of climax vegetation

	Vegetation types. . . .	Big sagebrush-Blue grama		Shadscale-Bluebunch wheatgrass		Greasewood-Western wheatgrass		Western wheatgrass-Silver sagebrush		Needle-and-thread-Big sagebrush		Ponderosa pine-Bluebunch wheatgrass		Big sagebrush-Needle-and-thread		Western wheatgrass-Sandberg bluegrass	
	Site numbers.	1		2		3		4		5		6		7		8	
Genus and species	Common name	Cover	Yield	Cover	Yield	Cover	Yield	Cover	Yield	Cover	Yield	Cover	Yield	Cover	Yield	Cover	Yield
Trees																	
Pinus ponderosa	Ponderosa pine	----	-----	----	-----	----	-----	----	-------	----	-------	23.0	-----	----	-----	----	-----
Shrubs																	
Artemisia cana	Silver sagebrush	0.2	-----	----	-----	----	-----	19.2	304.7	----	-------	----	-----	----	-----	----	-----
Artemisia frigida	Fringed sagewort	1.2	-----	0.8	-----	----	-----	----	-------	2.5	3.5	----	3.0	1.7	-----	0.8	30.0
Artemisia tridentata	Big sagebrush	6.4	66.7	4.5	32.3	9.2	134.3	----	-------	4.2	11.0	0.2	-----	10.8	37.5	----	-----
Atriplex confertifolia	Shadscale	----	-----	3.5	107.0	----	-----	----	-------	----	-------	----	-----	----	-----	----	-----
Chrysothamnus nauseosus	Rubber rabbitbrush	----	-----	2.2	63.0	----	-----	----	-------	----	-------	----	-----	----	-----	----	-----
Eriogonum multiceps	Wild buckwheat	----	-----	1.8	9.3	----	-----	----	-------	----	-------	----	-----	----	-----	----	-----
Eurotia lanata	Winterfat	2.7	35.0	0.8	-----	----	-----	----	-------	----	-------	----	-----	----	-----	----	-----
Gutierrezia sarothrae	Snakeweed	2.5	28.3	2.0	46.3	0.3	-----	----	-------	----	-------	1.3	-----	1.0	10.0	----	-----
Mammillaria vivipara	Ball cactus	----	-----	----	-----	----	-----	----	-------	----	-------	----	-----	----	-----	----	7.5
Opuntia polyacantha	Plains pricklypear	0.3	-----	----	-----	1.4	-----	----	-------	1.0	109.5	----	-----	----	-----	----	-----
Rhus trilobata	Skunkbrush	----	-----	1.2	61.7	----	-----	----	-------	----	-------	----	2.5	----	-----	----	-----
Sarcobatus vermiculatus	Greasewood	----	-----	1.7	-----	8.0	124.7	----	-------	----	-------	----	-----	----	-----	----	-----
Yucca glauca	Soapweed	----	-----	1.5	-----	----	-----	----	-------	----	-------	----	-----	----	-----	----	-----
Grasses and grasslikes																	
Agropyron smithii	Western wheatgrass	4.4	25.3	1.0	-----	21.5	301.7	49.2	658.0	8.3	123.5	3.0	12.0	5.8	36.5	25.5	203.5
Agropyron spicatum	Bluebunch wheatgrass	1.3	113.3	6.7	256.7	----	-----	----	-------	----	-------	9.5	217.0	3.5	101.0	----	-----
Agropyron trachycaulum	Slender wheatgrass	----	-----	----	-----	----	-----	4.5	11.3	----	-------	----	-----	----	-----	----	-----
Adropogon scoparius	Little bluestem	----	-----	2.2	-----	----	-----	----	-------	----	-------	1.0	29.0	----	-----	----	-----
Aristida longiseta	Red threeawn	----	-----	1.0	4.7	----	-----	----	-------	----	-------	----	-----	----	-----	----	-----
Bouteloua curtipendula	Side-oats grama	----	-----	----	-----	----	-----	----	-------	----	-------	6.5	59.0	----	-----	----	-----
Bouteloua gracilis	Blue grama	19.2	23.3	0.7	-----	9.7	65.0	----	-------	11.8	56.5	7.3	44.5	3.2	9.1	----	-----
Bromus commutatus	Hairy chess	1.0	2.3	0.3	5.3	3.5	34.7	----	-------	2.5	5.5	1.3	5.5	0.8	3.0	3.0	29.0
Bromus inerme	Smooth bromegrass	----	-----	----	-----	----	-----	0.7	146.3	----	-------	----	-----	----	-----	----	-----
Carex filifolia	Threadleaf sedge	1.2	13.3	0.8	-----	----	-----	----	-------	----	-------	0.3	-----	1.2	-----	0.3	-----
Koeleria cristata	Junegrass	0.8	50.7	1.0	16.3	0.2	4.3	----	-------	----	13.0	0.2	12.0	5.2	17.5	2.0	-----
Muhlenbergia cuspidata	Stonyhills muhly	1.0	-----	1.7	-----	----	-----	----	-------	----	-------	0.5	13.5	----	-----	----	-----
Oryzopsis hymenoides	Indian ricegrass	----	-----	0.8	-----	----	-----	----	-------	----	-------	----	-----	----	-----	----	-----
Poa pratensis	Kentucky bluegrass	----	-----	----	-----	----	-----	3.7	73.3	----	-------	----	-----	----	-----	----	-----
Poa secunda	Sandberg bluegrass	0.5	-----	----	-----	0.7	-----	----	-------	5.3	16.5	0.8	-----	----	6.0	7.3	16.0
Schedonnardus paniculatus	Texas crabgrass	6.6	-----	----	-----	----	-----	----	-------	----	-------	----	-----	----	2.0	0.5	-----
Stipa comata	Needle-and-thread	----	39.0	2.0	-----	----	-----	----	-------	20.8	110.0	6.2	24.5	7.5	37.5	0.2	-----
Stipa viridula	Green needlegrass	2.4	10.0	1.8	-----	4.7	74.3	4.2	102.3	----	-------	----	-----	----	-----	----	-----
Forbs																	
Achillea lanulosa	Yarrow	----	-----	0.3	10.0	2.0	25.3	3.0	105.7	----	13.5	0.2	-----	----	-----	1.3	24.0
Antennaria parvifolia	Pussytoes	----	-----	----	-----	----	-----	----	-------	----	5.0	----	-----	0.5	-----	----	-----
Aster multiflorus	Many-flowered aster	----	-----	----	3.0	----	-----	----	-------	0.2	-------	----	-----	----	-----	0.7	-----
Astragalus sp.	Loco	----	-----	2.5	9.0	----	-----	----	-------	----	-------	----	-----	----	-----	----	-----
Chenopodium sp.	Goosefoot	----	-----	----	-----	----	-----	1.7	17.0	----	-------	----	-----	----	-----	----	-----
Cirsium undulatum	Wavy-leaf thistle	----	-----	0.2	-----	----	-----	----	-------	----	-------	----	-----	----	-----	----	-----
Comandra umbellatum	Common comandra	----	-----	1.2	8.7	----	-----	----	-------	----	-------	----	-----	----	-----	----	-----
Erigeron sp.	Fleabane	----	1.0	----	15.3	----	-----	----	-------	----	-------	----	-----	----	-----	----	-----
Happlopappus spinulosus	Spiny sideranthus	0.2	-----	----	8.0	----	-----	----	-------	----	-------	----	-----	----	-----	----	-----
Lepidium densiflorum	Pepperweed	----	-----	----	-----	----	-----	----	-------	----	-------	----	-----	----	-----	T	1.2
Linum rigidum	Flax	0.2	-----	0.3	-----	----	-----	----	-------	----	-------	----	-----	----	0.2	----	-----
Lygodesmia juncea	Skeltonweed	----	-----	----	-----	----	-----	----	-------	----	-------	0.3	-----	----	-----	----	-----
Melilotus alba	White blossom sweetclover	1.5	-----	----	-----	1.7	-----	0.5	-------	----	-------	----	-----	----	-----	----	-----
	Moss	----	-----	----	-----	----	-----	----	-------	1.2	-------	----	-----	----	-----	----	-----
Oxytropis lambertii	Lambert's loco	----	-----	----	-----	----	-----	----	-------	----	-------	----	-----	0.5	5.3	----	-----
Petalostemum purpureum	Purple prairie clover	----	-----	----	5.7	----	-----	----	-------	----	T	----	-----	----	-----	----	-----
Phlox hoodii	Hood's phlox	0.3	48.3	0.8	26.0	----	-----	----	-------	----	-------	1.3	31.0	0.3	0.2	----	-----
Plantago purshii	Woolly Indianwheat	----	-----	----	-----	----	1.3	----	-------	----	T	----	T	----	-----	----	-----
Polygala alba	White polygala	0.7	6.3	----	1.0	----	-----	----	-------	----	-------	0.3	-----	----	-----	----	-----
Psoralea argophylla	Silvery psoralea	0.2	-----	0.3	-----	----	-----	----	-------	----	-------	----	-----	----	-----	----	-----
Sphaeralcea coccinea	Salmon-colored mallow	----	6.3	0.2	1.3	----	-----	----	-------	0.2	T	----	0.3	----	-----	----	-----
Taraxacum officinale	Dandelion	0.3	-----	----	2.7	----	9.3	----	16.7	----	-------	----	-----	----	-----	1.2	9.5
Tragopogon pratense	Oyster salsify	----	12.0	----	-----	0.2	6.3	----	-------	0.5	2.5	----	-----	----	-----	0.5	1.0
Vicia americana	American vetch	----	-----	----	-----	0.5	-----	----	0.7	----	-------	----	-----	----	-----	----	-----
	Unidentified forbs	0.3	-----	----	-----	----	-----	----	-------	----	-------	----	0.5	----	-----	----	-----
Total live cover (percent) and total vegetation yield (lb/acre)		55.4	481.1	45.8	693.3	68.9	781.2	83.7	1,436.0	58.5	470.0	63.2	454.3	42.0	265.8	43.3	321.7
Mulch		32.2	296.3	10.8	508.7	34.7	219.3	13.5	466.0	38.3	1,145.0	35.3	799.5	40.3	449.0	47.2	201.5
Bare soil		12.0		23.2		2.2		----		3.2		----		17.2		9.5	
Rock		0.3		20.2		----		----		----		1.5		0.3		----	
Estimated carrying capacity in acres per animal unit month			3.8		2.3		2.2		1.1		4.6		3.0		5.9		5.3
Range condition in percent			63		50		69		64		68		91		86		68

Two mapping units are shown (Figure 47) for midslopes between the ponderosa pine-bluebunch wheatgrass type and the alluvial valley floor occupied by the western wheatgrass-silver sagebrush type. The main criterion for separating the big sagebrush-blue grama unit from shadscale-greasewood type was the apparent larger amount of bare soil exposed in the shadscale-greasewood type. Also, the shadscale-greasewood type usually occurs on steeper slopes that represent the more highly erodible clay and silty shale beds of the Fort Union Formation. This topographic unit is sometimes referred to as "breaks" or "badlands" (Brown, 1971).

Sampling sites 1 and 7 (Figure 47, Table 44) were in the big sagebrush-blue grama type. Vegetation yields were medium (480 lbs/acre (538 kg/ha^2)) to low (270 lbs/acre (303 kg/ha^2)) and range condition low good (63%) to low excellent (86%). In general, the type may be described as a grassland with scattered shrubs.

Sampling sites 2 and 3 (Figure 47, Table 44) were in the shadscale-greasewood type; productivity of this type is higher than might be expected (690 to 780 lbs/acre (773 to 874 kg/ha^2)) but range condition is lower than for most other types (50 to 69%). More shrub species occur in this than in other plant communities.

The most productive (1,436 lbs/acre (1609 kg/ha^2)) of the plant communities sampled, the western wheatgrass-silver sagebrush (Site 4, Table 44) occurs on alluvium along the major drainages. Occasional flooding and shallow ground water contribute to this high productivity. This site is in excellent range condition (86%).

Using a weighted average based on extent of vegetation types and carrying capacity for each, it is estimated that about 13,000 acres (5261 ha) of this land would be required to support a cow herd of 300 head. This estimate also assumes some additional development of hay meadows.

MINING EFFECTS AND RECLAMATION ALTERNATIVES

Hydrology

The effects of surface mining on the area hydrology depend on the depth to which coal beds will be stripped and the areal extent of mine development. Two mining alternatives assume mining of the Anderson coal bed alone or mining of the Anderson plus one or two coal beds below the Anderson.

Surface mining of the Anderson will drain the saturated overburden and the Anderson coal bed adjacent to the mined area. The mine floor will be lower in altitude; therefore, the hydraulic gradient will be from the alluvium to the mine in most surface-mined areas. Water in the alluvium could be diverted into a mine even though surface mining did not extend to the alluvium. Assuming a surface mine approximated by a well one-half mile (.8 km) in radius, mine inflow is estimated by a form of Darcy's law to be less than 0.7 ft^3/s (.02 m^3/s). However, this flow should gradually diminish to less than 0.1 ft^3/s (.003 m^3/s) as hydraulic gradients approach equilibrium conditions.

The area of greatest water-level decline in wells can be expected to be to the east, upgradient from any potential surface mine. Depending upon the extent of mining, 17 stock wells or springs could become dry. Replacement wells of similar yields could be completed in one or more water-bearing zones of the Tongue River Member. The water quality generally could be expected to be better than water from wells presently in alluvium.

East Trail Creek and its intermittent tributaries will continue to be losing streams in the study area as the alluvium is drained by mining. Intermittent streamflow is likely to be slightly decreased as water infiltrates to the alluvium. Streamflow downstream from the study area could be increased if mine drainage is returned to East Trail or Trail Creek. Because the stream would be above the water table, the drainage would likely infiltrate into the alluvium or clinker over a short distance. As discussed above, however, channel erosion would need to be prevented at points of reintroduction during periods of heavy dewatering and heavy rainfall.

Floodwater would need to be diverted around a mine. Diversion works would need to be designed to carry the natural sediment load as well as to be noneroding. Diversion channels could be designed to minimize infiltration.

Post-mining water-quality changes are to be expected in both surface and ground water. Surface-water quality downstream from a potential mine could be degraded by poor quality water from mine drainage and by sedimentation or erosion in the event of improper flood control diversion.

Spoils from strip mining also could cause changes in ground-water quality. The character of these changes is difficult to predict without mineralogical data of the replaced spoils. However, recharge to existing

shallow aquifer units through replaced spoils during post-mining conditions may be small. Even so, placement of toxic materials and hazardous overburden minerals between the soil zone of oxidation and the present level of ground water should mitigate adverse alterations of ground-water quality caused by toxic spoils. The active mine will act as a discharge area for shallow ground water; however, any water polluted by mining operations, such as by explosives or by fuel and oil spill, may percolate to deeper aquifers in areas where the head gradient is downward.

Water problems associated with surface mining the Anderson plus one or two other coal beds would be similar, but more extensive than if the Anderson alone were mined. A deeper mine would extend farther into the alluvium and would produce more water. Probably more than twice as much water would be produced from the mine and its disposal would have to be controlled to prevent downstream erosion. Water levels in the alluvium downstream from the area would be lowered more severely, which could decrease hay production and injure plants whose roots extend to the water table.

Reclamation of spoils appears to be possible using seasonal precipitation alone. Revegetation on the spoil piles can be improved by surface conditioning and top-soiling. Surface conditioning reduces surface runoff and maximizes utilization of precipitation. Top-soiling maximizes use of pre-existing soil.

Sediment Yields

The following discussion is based on the assumption that, if the area is mined, the primary post-mining use will be rangeland.

The assumption was also made that, if the area is mined, it will be graded, covered with topsoil or otherwise suitable growth media, and seeded with adapted grasses. Close-spaced contour furrowing, as discussed by Branson, Miller, and McQueen (1966), or gouger pitting, as discussed by Sindelar and others (1974), may be necessary to control runoff from and erosion of soils that are silt loam or finer-textured or any soil that is compacted. Implementation of these practices would reduce the frequency of floods that would be large enough to damage the post-mining channels and valley floors and would minimize the chance of increasing sediment loads downstream from the area.

An important problem to contend with in the rehabilitation plan for the area is that much of the land surface will be lowered by mining. This will occur because, in those areas where the overburden is less than about 150 ft (46 m) thick, the overburden will not expand enough to fill the void left by excavation of the coal bed which is approximately 30 ft (9 m) thick. This will result in a depression in lower parts of the mined area where the overburden is thinnest. If this depression is not filled with earth materials, at least so that streams can cross the depression, ponds will form in the lowest parts.

Anywhere that the gradients of stream channels are increased after mining, such as where the channels enter a lowered area, there is potential for the initiation of gully erosion which would migrate headward in the alluvium upstream from the mined area. The resulting gully would drain ground water from the alluvium and thus deteriorate the productivity of the valley floor.

The lowering of the land surface may require that channels be stabilized by cutting and filling to minimize increases in gradients and/or by constructing widened channels where the gradients are increased so that normal flows would be relatively shallow. Also, most channels of East Trail Creek have gradients that are steep enough to cause erosion in channels of the same widths that were situated in unstable materials such as newly placed spoils and soils. Lining the channels may be necessary to control erosion in some places where the gradients are increased. A thorough discussion of the hydrologic effects of a lowered land surface appears in the final environmental impact statement for mining that is planned near Decker, Montana (USDI, 1977a).

Another potential problem, which could result in large increases in sediment discharge below the mining area, involves the diversion of the channels of Trail Creek and East Trail Creek if the coal underlying those valley floors is mined. Diversion channels located at one side of the valley floor would have steeper gradients because they would be relatively straight as opposed to the meandering of the natural channels. Installation of stable linings and/or drop structures as discussed in the previously mentioned environmental impact statement (USDI, 1977a) would minimize erosion and sedimentation problems in diversion channels.

Implementation of the erosion-control measures that were discussed and installation of sediment retention ponds immediately downstream from raw-spoil banks and other areas where erosion cannot be controlled should minimize any increase in sediment discharge to Hanging Woman Creek. Retention ponds may not be needed after a period of perhaps 10 years when perennial grasses have come into equilibrium with their environment and stable soil structure has reestablished. Any drop structures or channel linings may require periodic maintenance in order to remain functional in the future.

Climate

There is sufficient precipitation to support reclamation efforts. Irrigation would not be required except perhaps in the driest years. The cost of irrigation, however, could probably not be justified on this basis. It would probably be more economically reasonable to have an occasional failure and replanting than plan large-scale continuous irrigation.

The area does have a relatively short growing season, however. This factor will probably be the greatest single constraint to reclamation success. As shown in Figure 10, only July and August are free from average minimum temperatures less than 32° F. This implies less than 90 continuous

frost-free days. Mean monthly temperatures are greater than 32° F from May through October (Figure 9) suggesting a growing season less than 180 days. The actual growing season, depending upon plant species is from 90 to 180 days.

There is sufficient snow in the area to consider the possibility of shaping spoil to trap snow. This would have the effect of delaying melt and increasing soil moisture availability into the spring and summer.

Soils

It is important that productive topsoil is saved to replace on the land surface following mining. A productive topsoil contains the properties necessary to obtain a rapid and effective revegetation. Revegetation is more rapid and permanent, and site stability is more certain with the use of a fertile topsoil with good water infiltration and holding properties. Also, the final soil cover will determine future potential use and management needs of the land following mining. Therefore, care must be taken to select the most suitable topsoil material available for final placement on the mined land surface.

Soil depth needed on the reconstructed land surface will depend primarily upon the future use of the land. If the land is to be used for agriculture, the land should be reconstructed with a depth of soil suited to the rooting depth of crops adapted to the area.

If the land is to be returned to grazing land, the annual depth of moisture penetration in a typical soil would be a reliable criteria to determine soil depth needed. In many situations, this will be the same as the depth of lime accumulation in the soil.

As discussed previously, soil moisture penetration ranges from 8 inches (20 cm) to 33 inches (84 cm) in some of the deeper soils. In some of the shallower soils on breaks and gently sloping uplands, soil moisture penetrates the entire profile. This would suggest that topsoil should be replaced to these depths if reconstruction of the specific site is the reclamation goal.

Criteria used to evaluate topsoil sources was taken from BLM Manual 7312, Illustration 8, page 9, Table 13, "Suitability Ratings of Soils as Sources of Topsoil". These are the same criteria standards as used by SCS. Poor topsoil sources are those soils that are high in clay, coarse fragments, sodium or total soluble salts.

Seven percent of the acreage lacks a suitable source of topsoil. This includes the rock outcrop, shale outcrop as well as the Kyle and Pierre clays.

One-third of the area (32%) is covered with soils that are a very shallow source of topsoil (less than 10 inches (25 cm)). This includes primarily the Midway and Heldt series.

However, there is a large source of topsoil material from moderately deep and deep soils in the study area. These are primarily the Thedalund, Thurlow, and McRae series. All available topsoil material (including suitable material within 60 inches (152 cm) of the surface) is of sufficient quantity to cover the study area 20 inches (51 cm) deep.

Previous EMRIA studies in Montana (at Otter Creek and Bear Creek) have shown an ample supply of suitable topsoil substitute material, usually near the surface of the overburden. The exact location of this borrow material must be located within a detailed inventory prior to mining. According to the section in this report on overburden chemistry and mineralogy by USGS, there should be more than sufficient overburden material on this study area to use as a soil substitute.

Reconstruction of the mine land provides an opportunity to make the land more productive and more useful than before mining. This is done by (1) shaping the spoils to suit the intended use of the land, and (2) replacing present shallow soils with a soil depth that will allow vegetation a normal response to climate.

The chemical composition of the soils appears to be favorable for stockpiling and land reclamation. The only exceptions are the soil series, Arvada, Bone, and Vananda. These three soil series are judged on the basis of the taxonomic description to be a poor-to-unsuitable topsoil resource because of high salinity. This salinity condition, however, was not confirmed by chemical analysis. A conservative stance would be not to use soil materials from these series as top dressing but to bury them at a depth beyond plant roots. All of the other soils in the study area are alkaline in reaction. The overall trace-element composition of soils in the study area is similar to soils developed on the Fort Union Formation in other parts of the Northern Great Plains (U.S. Geological Survey, 1976, p. 57-81) and in the Powder River Basin of Montana-Wyoming (Tidball and Ebens, 1976). Soils throughout the region are widely used for range, pasture, and small grains without ill effects except for very local salinity-problem areas.

Other soil series in soil group 1 (Figure 25) may have at least moderate salinity conditions in the subsoil. These materials should either be buried at a depth beyond normal plant-rooting depth or should be diluted by mixing with nonsaline materials. If the mine-reclamation plan can provide for temporary irrigation for the first few years, then saline materials should be placed in the lower parts of the valley where irrigation water may be more readily available to leach the soil. Final surface grading of materials with potential salinity should leave only very gentle slopes so that leaching water will percolate downward in the profile rather than laterally downslope, thus leading to the development of a saline-seep area elsewhere.

In some situations, it would be desirable to have a buffer layer of soil material (or suitable substitute material) between the topsoil and the overburden. This would occur if saline or sodic overburden is located

at the surface of the reshaped overburden. Research conducted by the ARS, USDA, Mandan, North Dakota, has found sodium to migrate upward (about 6 inches (15 cm) in 3 years) from a sodic overburden to a nonsodic topsoil. Therefore, in such cases, a compensating buffer layer of subsoil, or a layer of low salt, low sodium overburden would be desirable. A generous layer of soil material replaced on the surface would accomplish the same thing.

The reshaping of spoil-material contours should provide for moderate slopes particularly on south and southwest aspects. These slopes represent some of the more severe survival conditions for plants because of the excessive soil temperatures that are possible, and because the limited precipitation that is typical of the region is subject to excessive runoff if the slopes are too steep.

Careful consideration should be given to plans for reconstruction after mining of bottomlands now occupied by trenched channels and adjacent alluvial terraces. Deepening and widening of the channel of Trail Creek has eliminated frequent flooding of adjacent lands. The channel bed now appears to be aggrading. Grass and shrubs growing in the channel reduce the rate of flow causing sediment to accumulate as discussed by Hadley (1961). If the trenched channel continues to fill with sediment, flooding of adjacent lands will be more frequent; consequently, a smaller channel with wider meanders would develop over and adjacent to the present channel. Channel plugs have been used in the past to hasten this process (Hadley and McQueen, 1961). Land management agencies have constructed floodwater spreaders at several locations in the Northern Great Plains to achieve the same results (Miller and others, 1969).

A logical plan for reconstruction of valley floors would consider optimum use of floodwaters and entrapment of sediment. Analysis of data acquired at the various study sites provide insight as to how to best use available resources to accomplish this purpose. Grasses rather than the shrubs now occurring in the area should be planted if optimum forage production from the flood plain and low terraces is desired. Grasses characteristically occupy areas that are frequently flooded (Figure 34). Western wheatgrass, which is native to the area, is capable of withstanding up to one foot of sediment deposition per year (Hubbell and Gardner, 1950).

Silver sagebrush now occurs on alluvium with low to moderate moisture-retention capabilities (Figures 30 and 31) while greasewood occurs on alluvium with higher retention capabilities (Figures 30 and 32). Ground water is apparently utilized by both species, with indications that their roots transport and supply water for recharge of soil some distance above the water table. Before mining, these shrubs could be used as indicators to help delineate alluvial deposits with different moisture-retention capabilities. As a result, different materials could be stockpiled separately.

Highly retentive alluvium associated with greasewood should be considered for use in reconstructing the flood plain. There is evidence

(Miller and others, 1969; Branson, Miller, and McQueen, 1970) that such fine-textured alluvium can support a good cover of western wheatgrass if flooded frequently.

Moderately retentive alluvium associated with silver sagebrush should be considered for positioning on reshaped uplands; there is evidence (Shown, Miller, and Branson, 1969) that, when sagebrush has been eradicated from similar soils, grass can simply be seeded and established. This could eliminate the need to hold water on the surface by furrowing, as would be required if highly retentive soil is placed at the surface on upland areas (Branson, Miller, and McQueen, 1966).

Reconstruction of upland soils with properly selected materials can result in more efficient utilization of soil moisture by vegetation than that which usually occurs under natural conditions. This is indicated by evidence obtained from sites illustrated in Figures 34 and 35. At some of these sites, bedrock encountered at different depths impedes drainage causing moisture to be stored in thicker than normal films. The force with which moisture is adsorbed decreases 2.46 times for each additional molecular layer of water adsorbed (Miller and McQueen, 1978). Consequently, water is more readily obtained by vegetation. Under these conditions, less hardy but more productive species of vegetation occur under natural conditions.

Placement of required depths of loamy soil over properly compacted finer materials, as previously proposed, can result in more efficient use of soil moisture by vegetation. Available fine-textured materials should be used to cover unweathered spoil. This finer material should be compacted to the degree where void-moisture capabilities (VMC's) determined from volume weight (VW) measurements, as illustrated in Figure 27, are less than the moisture-retention capabilities (MRC's) of the materials. Moisture-retention capabilities of materials can be readily evaluated using the filter paper method of McQueen and Miller (1968), illustrated in Figure 29 and the modeling technique of McQueen and Miller (1974), also illustrated in Figure 29. Fifteen atmosphere moisture content data, characteristically published by the U.S. Soil Conservation Service, can also be used in conjunction with the modeling technique of McQueen and Miller (1974) to define moisture-retention capabilities (MRC's) of soils.

With the moisture-retention capability (MRC) of available soil material at hand, the depth of soil that must be repositioned to obtain desired results can be determined. The depth of loamy material that must be deposited over finer-textured base material will also be dependent on the degree of compaction. Once the amount of water likely to infiltrate is determined, the depth of material with a given retention capability (MRC) and the volume weight (VW) needed to achieve desired results can be determined. The maximum depth of water stored in upland soils averaged 10 inches (25 cm) at sites sampled in the Hanging Woman study area. This value includes data from sites where snow blows off and data from sites where wind-blown snow accumulates. Snow movement could be minimized by properly shaping the land and managing the vegetation for moderate to

high stubble length. Also, upland soils could be reconstructed to store 10 inches (25 cm) of water when wetted to the adsorption-moisture capacity (AMC) (16 molecular layers of water).

Under these conditions, six molecular layers of water are adsorbed to particle surfaces in excess of the 10 layers present when unimpeded drainage stops at the moisture-retention capability (MRC) level. Maximum levels of storage would probably not be achieved except during the wettest years; nevertheless, storage of some water in excess of 10 molecular layers would probably occur during all but the driest years. As a result of increased water availability, midgrasses rather than shortgrasses should dominate the reconstructed area. If the area is not overgrazed, this taller vegetation should also help hold snow where it falls.

Compaction, resulting from repositioning of soil with machinery, can result in volume weights (VW's) that do not provide sufficient void space for infiltration and storage of water (Sindelar and others, 1974); consequently, the volume weight (VW) that must be achieved to permit storage at adsorption-moisture capacity (AMC) levels must be determined prior to positioning of materials. For example, if retention capability (MRC) of the loamy material used to reconstruct the solum is 10%, the adsorption capacity (AMC) will be 16%. The volume weight (VW) required to produce a void-moisture capacity (VMC) of 16% can be determined from the linear relationship between volume weight (VW) and void-moisture capacity (VMC) presented in Figure 27. For the material used in this example, a volume weight (VW) of 114 lb/ft^3 (1.82 g/cm^3) would provide the required void space.

Lower volume weights (VW's) would be necessary to provide the proper void space in soils with higher moisture retention capabilities (MRC's). If a soil is too compact after emplacement, the required voids can be created by causing a total of 10 inches (25 cm) of water to accumulate in the soil. This could be accomplished by a series of sprinkler irrigations, or perhaps by causing snow to accumulate behind a set of movable snow fences. The fence could be relocated after desired results are obtained. If soils with high retention capabilities (MRC's) must be used instead of loamy materials, catchments should be created at the surface with an Arcadia furrower as recommended by Branson, Miller and McQueen, (1966).

Moisture regimes occurring in breaks (Figure 35) and foot slope areas (Figure 36), will be difficult to reestablish because of the complexity of these areas caused by variable erosion and deposition of sediments and variable depths to parent rock. The steep slopes, characteristic of breaks, could probably not be maintained unless resistant rocks were deposited there rather than softer soil materials. The parent rock encountered at the base of soil profiles tends to disintegrate readily when saturated with water. Some desirable soil materials may be available from this source. Moisture-retention characteristics of these materials can be defined by techniques described in this report.

Overburden

If there is not sufficient topsoil at the site, then the overburden rock will have to be considered as a substitute.

Perhaps the single most important statement to be made about the lack of potential chemical harmfulness of a potential soil replacement material (overburden rock) is that it is chemically and mineralogically similar to soils of the region which successfully support desirable stands of the native vegetation. The sandstone, and to a somewhat lesser extent the siltstone-plus-shale, at the Hanging Woman study site is similar in bulk chemistry to the subsoils at the study site and the rest of the Fort Union region. The comparison is made in Table 16.

Judged only from bulk chemistry of rock and soil samples, it appears that much of the overburden rock at the Hanging Woman Creek study area could be used to replace the soils of the site or region. It is, however, probable that the pulverized overburden, during its process of chemical weathering and physical alteration in its new, near-surface environment, would release different quantities of chemical substances than would the natural soils: the pulverized rock could be expected to release either more or less, depending on the substance at its mineralogical form in the rock. These questions of the amounts of chemical substances which would be released by pulverized overburden material used as soil replacement can only be resolved by studies of chemical-leach elemental availability, by studies of physical properties and breakdown, and perhaps by plant uptake studies conducted on the pulverized rock material.

We plan to conduct availability tests on the samples of this study. The equally important study of physical properties and physical alteration with time must come from other workers. At the present limited stage of knowledge of reclamation chemistry and toxicity of elemental concentrations in soil, we feel that it is a very complex matter to set actual "red flag" or hazard level concentration limits in soils for particular elements. Some progress has been made in this matter for certain elements, most notably molybdenum and selenium, but for these and almost all other elements of interest, different soil conditions and even different points of view have the strongest influence on the assignment of maximum permissible levels. Varying soil pH, mineralogy, moisture regime, and temperature, as well as the varying uptake abilities of different plant species and the hardiness and dietary preferences of various animal species, must be taken into account in determining acceptable ranges of whole-soil concentrations of chemical elements. The situation is only somewhat simpler for determining acceptable <u>availability</u> levels of the elements.

In addition to chemical suitability of overburden rock, the relative volumes of rock types must also be considered. Table 45 shows the relative volume abundance of the lithologic constituents of the rock column at the Hanging Woman Creek study area, both by individual hole cores and for all cores taken together.

Table 45. Abundance, in percent, of different rock types (Fort Union Formation) in cores of drilled holes at Hanging Woman Creek study area.

Hole Number	Sand-stone	Silt-stone	Shale and mudstone	Dark shale	Coal
20	14	26	23	9	16
21	39	14	17	5	25
23	18	18	31	12	20
25	22	9	31	13	26
27	42	15	19	8	16
All core	28	16	24	10	22

In general, sandstone is sufficiently abundant (about one-third of the overburden rock) and is present in sufficiently thick, continuous and recognizable units to be used as the sole type of overburden reclamation material wherever that would seem desirable, as for a plant growth medium on the top of the refill column, or for the material most likely to contact ground water at the bottom of the refill column. In much of the overburden rock column, strata of siltstone are sufficiently thick to be treated in the same way, if desired. Units of dark shale and other shale are more commonly intermixed with each other and with sandstone and siltstone over short vertical distances, but the relative volumes of either pure or intermixed zones of shale are small enough that these rocks could practically be segregated into the middle part of the refill material and separated from both plant roots and the ground water zone by a thickness of sandier rock at top and bottom.

Other USGS studies are being conducted to assess the effects that may occur through surface mining on plants themselves, rather than indirectly via availability measurements of the spoil materials. Erdman and his colleagues (Erdman and Ebens, 1975; Erdman and Ebens, 1976; Erdman, Ebens, and Case, 1978; Erdman and Gough, 1978) have reported that spoil material, even with topsoil added, affects the element concentrations of plants to a significant degree relative to plants grown in undisturbed areas. Some of these effects may be beneficial; others could pose some nutritional problems to animals feeding on the plants. These conclusions are based on studies of sweetclover, several cool-season grasses, alfalfa, and wheat (plants commonly used in reclamation) sampled from reclaimed lands of selected mines and from "control" areas in the Northern Great Plains coal region.

These studies tend to corroborate an earlier report by Sandoval and others (1973), which found the phosphorus available to plants to be very low in spoil materials from the Northern Great Plains. Conversely, zinc concentrations appear to be increased in plants growing on spoils, an effect that may be beneficial. A potential range management problem arising from use of forage plants growing on spoil is that the copper:molybdenum ratio in such plants is rather consistently less than about two, the value below which molybdenosis is considered likely to affect ruminants, particularly cattle.

Without leach-availability or plant-uptake studies at the Hanging Woman Creek study area, it is not certain that the findings of Erdman and his colleagues would apply; but from the wide spatial distribution of their samples, and the similarity of rocks of the Hanging Woman Creek study area to others of the region, discussed in this paper, it seems reasonable that they should.

The mineralogy of the soil materials does not suggest any problems of slope instability with the possible exception of those soils that may have a combination of abundant montmorillonite and available sodium ions. The sodium-saturated clay is subject to enhanced expansion and contraction as the clay undergoes a wetting-drying cycle. Such high-sodic clays should be selected and placed on only level to moderate slopes and beyond the depth of plant roots.

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APPENDICES

APPENDIX A

ENGLISH TO METRIC (SI) CONVERSIONS

A dual system of measurements--English units and the International System (SI) of metric units--is given in this report. SI is a consistent system of units adopted by the Eleventh General Conference of Weights and Measures in 1960. Selected factors for converting English units to SI units are given below.

Multiply English units	by	To obtain SI units
Inches	2.40	centimeters (cm)
Feet	0.3048	meters (m)
Miles	1.609	kilometers (km)
Pounds	453.60	grams (g)
Ton	0.9072	tonne (t)
Acres	0.4047	square hectometers (hm^2)
Square Miles	2.590	square kilometers (km^2)
Gallons	.003785	cubic meters (m^3)
Acre-feet	.001233	cubic hectometers (hm^3)
Feet per mile	0.1894	meters per kilometer (m/km)
Inches per hour	2.54	centimeters per hour (cm/h)
Feet per day	.3048	meters per day (m/d)
Pounds per square inch	70.31	grams per square centimeter (g/cm^2)
Bars	1019.78	grams per square centimeter (g/cm^2)
Pounds per cubic foot	0.01602	grams per cubic centimeter (g/cm^3)
Pounds per acre	1.1206	kilograms per square hectometer (kg/hm^2)
Feet squared per day	0.0929	meters squared per day (m^2/d)
Cubic feet per second	0.02832	cubic meters per second (m^3/s)
Gallons per minute	0.06309	liters per second (l/s)

APPENDIX B

Weather Data Summary for Otter 9-SSW*; Lat. 45°06'; Long. 106°15'; 4100 MSL; Period of Record 1961-1976.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Temperature												
Mean Maximum (°F)	30.11	38.09	45.2	56.62	67.11	76.4	82.08	86.7	73.61	61.45	44.79	34.31
Mean Minimum (°F)	9.51	16.7	21.27	31.32	40.67	48.87	55.94	54.26	43.76	34.9	23.53	14.43
Mean Monthly (°F)	19.84	27.41	33.27	44.0	53.91	62.65	71.53	70.51	58.5	48.2	34.14	24.39
Mean High (°F)	50.8	53.06	65.93	76.26	84.86	91.78	97.85	99.46	90.46	80.81	64.5	53.37
Mean Low (°F)	-17.2	-6.6	.8	17.13	23.93	37.0	44.87	42.0	30.23	18.75	3.31	-11.43
Mean > 90 °F (days)	0	0	0	0	.35	1.78	11.14	11.06	2.07	.06	0	0
Mean < 32 °F (days)	27.8	24.86	26.93	17.73	4.33	.2	0	0	2.8	11.56	23.0	
Total Average Precipitation (average)	1.13	.76	1.09	2.89	2.48	3.50	1.44	1.31	1.51	1.44	.95	.95
Total Average Snowfall (inches)	8.0	0	0	11.0	0	.87	0	0	0	.71	2.5	4.5
Greatest Snowdepth (inches)	8.86	7.13	4.6	4.86	1.33	0	0	0	.73	1.31	4.37	4.81
Days with Hail	0	0	0	.13	.66	.86	.73	.13	.2	0	0	0

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis

Sample	Si %	Al %	Ca %	Mg %	Na %	K %	Fe %	Ti %	Mn %	Ag ppm
Sandstones										
HWC20S1	21	3.2	13.47	2.34	0.68	1.22	2.63	0.24	0.068	0.15
HWC20S1X	21	3.7	14.24	2.54	0.70	1.21	2.48	0.23	0.058	0.25
HWC20S2	23	3.6	10.61	3.52	0.74	1.14	2.82	0.28	0.058	0.15
HWC20S2X	23	3.7	10.69	3.49	0.72	1.21	2.81	0.29	0.057	0.15
HWC20S3	33	6.1	2.10	1.23	0.96	1.85	1.83	0.33	0.039	0.32
HWC20S3X	32	5.8	2.07	1.18	0.95	1.78	1.79	0.32	0.026	0.23
HWC20S4	28	5.4	2.03	0.81	0.82	2.03	7.14	0.31	0.048	0.21
HWC21S1	32	5.7	3.22	1.33	1.03	1.80	1.62	0.37	0.055	0.24
HWC21S1X	32	6.1	3.39	1.31	0.98	1.97	1.67	0.36	0.040	0.15
HWC21S2	34	4.9	0.99	0.52	1.08	2.27	1.84	0.22	0.050	0.21
HWC21S3	35	4.9	1.01	0.57	1.04	2.25	1.90	0.21	0.047	0.15
HWC21S4	31	4.7	1.33	0.70	0.87	2.03	5.30	0.25	0.092	0.14
HWC23S1	27	6.3	4.34	1.57	0.86	1.70	2.70	0.37	0.026	0.29
HWC23S1X	28	6.2	4.69	1.58	0.84	1.94	2.77	0.38	0.073	0.49
HWC23S2	31	5.3	3.58	1.36	0.93	1.62	1.99	0.33	0.066	0.26
HWC23S3	20	3.0	12.47	4.30	0.67	1.12	2.82	0.26	0.041	0.49
HWC23S3X	20	3.4	12.15	4.24	0.69	1.03	2.85	0.26	0.044	0.23
HWC23S4	17	2.8	13.41	5.08	0.67	0.91	2.17	0.19	0.027	0.25
HWC23S4X	18	3.1	13.69	4.98	0.68	0.94	2.32	0.22	0.027	0.15
HWC27S1	39	3.2	0.46	0.29	0.55	1.68	1.16	0.22	0.027	0.15
HWC27S2	31	5.5	3.35	1.52	1.05	1.51	1.81	0.45	0.026	0.31
HWC27S3	30	5.2	3.29	1.52	1.06	1.52	2.45	0.32	0.047	0.15
HWC27S3X	29	8.2	1.10	1.52	1.06	2.31	3.08	0.41	0.100	0.15
HWC27S4	31	5.8	4.17	1.41	1.05	1.52	1.55	0.38	0.026	0.32
Siltstones and shales										
HWC20T1	31	7.4	1.07	1.23	0.88	2.44	2.70	0.42	0.038	0.24
HWC20T1X	30	7.3	1.00	1.17	0.86	2.29	2.52	0.39	0.026	0.39
HWC20T2	25	6.9	2.92	1.55	0.72	2.59	5.36	0.38	0.124	0.45
HWC20T3	27	8.8	2.18	1.49	0.77	2.90	2.86	0.41	0.063	0.80
HWC20T4	32	6.6	0.57	0.67	0.52	2.21	1.96	0.38	0.026	0.40
HWC20T4X	31	7.4	0.56	0.69	0.51	2.34	2.00	0.39	0.026	0.34
HWC21T1	27	6.8	2.98	1.54	0.88	2.36	3.69	0.42	0.074	0.40
HWC21T2	26	7.3	2.56	1.55	0.88	2.58	4.74	0.39	0.071	0.54
HWC21T3	30	5.1	3.21	1.55	0.89	1.50	2.49	0.32	0.046	0.42
HWC21T4	30	7.6	0.73	0.85	0.65	2.58	2.14	0.42	0.026	0.49
HWC23T1	26	6.3	4.91	1.73	0.65	2.13	3.40	0.40	0.090	0.33
HWC23T1X	26	6.3	5.05	1.75	0.64	2.30	3.47	0.39	0.083	0.55
HWC23T2	30	8.1	0.66	1.11	0.90	2.98	2.30	0.42	0.026	0.52
HWC23T2X	30	8.5	0.74	1.11	0.88	3.00	2.20	0.42	0.026	0.39

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	As ppm	B ppm	Ba ppm	Be ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	F ppm	Ga ppm
					Sandstones-continued					
HWC20S1	0.1L	11	267	1.14	48	5.0	35	6.6	400	9.4
HWC20S1x	3.0	13	326	1.45	36	4.8	41	6.8	700	7.1
HWC20S2	3.1	24	300	1.33	34	5.2	51	8.0	500	9.9
HWC20S2x	2.9	18	256	1.06	38	4.3	37	7.8	400	8.3
HWC20S3	4.5	31	826	1.89	97	15.8	63	13.6	600	16.7
HWC20S3x	1.8	28	605	1.86	22	15.9	59	15.7	400	19.4
HWC20S4	48.7	32	350	1.58	44	12.8	95	22.3	400	15.6
HWC21S1	8.3	45	469	1.57	35	10.7	95	19.9	600	12.7
HWC21S1x	6.9	36	611	1.21	91	9.9	62	22.4	600	12.9
HWC21S2	6.7	33	529	2.24	49	13.9	84	13.9	400 L	14.6
HWC21S3	3.1	17	596	1.90	41	7.5	74	12.5	400 L	14.9
HWC21S4	3.6	19	370	2.60	56	15.2	104	18.7	400	14.7
HWC23S1	8.7	46	396	2.10	101	10.7	68	62.0	700	15.3
HWC23S1x	5.1	49	554	2.14	94	13.1	90	54.8	700	21.9
HWC23S2	5.5	39	343	1.30	98	8.6	64	16.4	500	14.6
HWC23S3	2.8	15	334	1.03	34	2.2	42	10.2	400	11.6
HWC23S3x	2.4	18	304	1.08	51	1.6	34	7.5	500	7.1
HWC23S4	1.8	14	267	0.80	39	1.7	34	6.4	600	6.1
HWC23S4x	2.4	14	276	0.83	59	1.8	34	6.9	400	6.2
HWC27S1	3.1	38	391	1.12	68	4.2	27	5.8	400 L	6.1
HWC27S2	6.3	39	634	1.04	77	10.6	114	13.6	500	13.6
HWC27S3	5.2	33	450	1.66	42	9.1	82	13.3	700	13.4
HWC27S3x	5.2	34	459	1.93	61	8.3	89	12.8	900	13.1
HWC27S4	5.4	33	426	1.05	45	10.8	73	16.5	500	14.8
					Siltstones and shales-continued					
HWC20T1	3.5	55	730	2.52	47	15.8	100	75.0	800	23.7
HWC20T1x	3.7	64	705	2.51	33	14.1	97	80.4	800	23.7
HWC20T2	3.1	57	880	3.13	53	11.3	106	69.5	900	28.2
HWC20T3	11.1	61	591	2.31	37	15.0	99	54.5	1000	26.1
HWC20T4	9.1	56	336	2.46	22	7.4	89	56.0	800	23.4
HWC20T4x	7.9	59	397	2.31	49	8.5	106	67.8	400 L	23.3
HWC21T1	6.7	61	549	3.21	0 B	15.2	112	73.7	900	24.9
HWC21T2	4.4	56	546	3.23	64	18.8	104	76.5	900	30.2
HWC21T3	4.9	51	502	2.28	87	13.1	91	58.7	800	17.9
HWC21T4	62.2	68	366	3.04	77	14.7	104	54.2	900	25.4
HWC23T1	6.4	61	429	2.53	51	13.2	93	65.6	800	19.3
HWC23T1x	3.4	65	481	2.93	78	16.8	112	71.6	700	24.5
HWC23T2	8.9	58	744	2.86	64	17.4	126	63.7	1000	33.9
HWC23T2x	11.4	61	501	2.93	14	16.0	105	42.1	1000	30.8

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Ge ppm	Hg ppm	La ppm	Li ppm	Mo ppm	Nb ppm	Ni ppm	Pb ppm	Rb ppm	Total S%
Sandstones-continued										
HWC20S1	0.48	0.04	29	9.5	3.2	2.2	15.1	0.79	39	0.053
HWC20S1X	0.66	0.02	20	5.9	2.7	5.8	12.8	0.83	42	0.055
HWC20S2	0.59	0.02	23	8.8	4.4	2.7	16.8	0.82	37	0.100
HWC20S2X	0.73	0.02	17	8.8	2.0	5.1	15.2	0.82	32	0.055
HWC20S3	1.11	0.02	38	18.4	9.8	7.6	55.1	7.18	68	0.149
HWC20S3X	0.79	0.03	41	22.0	5.9	8.0	56.5	6.44	48	0.150
HWC20S4	0.58	0.10	29	19.6	8.8	4.1	63.2	14.82	51	0.819
HWC21S1	1.16	0.04	27	23.2	4.0	8.8	36.3	4.17	51	0.139
HWC21S1X	1.09	0.03	33	20.5	6.6	9.8	31.6	3.52	77	0.143
HWC21S2	1.98	0.05	28	14.2	4.2	8.8	70.0	11.34	83	0.152
HWC21S3	0.87	0.02	32	15.6	4.2	10.5	25.9	12.34	84	0.093
HWC21S4	1.46	0.07	34	23.1	12.5	3.8	44.4	11.08	74	0.241
HWC23S1	0.80	0.06	32	22.2	8.1	5.9	40.1	6.19	68	0.054
HWC23S1X	0.71	0.03	41	22.0	9.7	4.3	47.5	9.85	81	0.136
HWC23S2	1.04	0.03	25	19.3	5.0	4.8	29.1	5.38	48	0.215
HWC23S3	0.45	0.02	28	7.8	5.5	3.9	9.0	2.23	38	0.055
HWC23S3X	0.40	0.03	29	4.9	3.8	6.0	5.9	0.82	33	0.055
HWC23S4	0.35	0.02	23	7.9	2.0	4.0	5.9	0.83	25	0.055
HWC23S4X	0.58	0.02	21	3.4	3.1	4.7	6.6	0.82	32	0.055
HWC27S1	0.56	0.03	30	13.7	2.2	3.7	11.9	3.94	59	0.269
HWC27S2	0.99	0.04	40	17.4	4.6	6.0	41.1	2.83	47	0.147
HWC27S3	0.94	0.02	26	10.5	7.5	6.8	35.3	5.41	56	0.135
HWC27S3X	0.94	0.03	23	10.5	6.9	6.6	35.6	3.71	56	0.525
HWC27S4	0.67	0.03	43	14.4	11.5	6.2	36.7	3.90	47	0.110
Siltstones and shales-continued										
HWC20T1	1.43	0.09	39	35.4	8.4	7.7	63.0	18.11	106	0.093
HWC20T1X	1.17	0.06	39	27.4	9.8	4.2	58.4	15.48	55	0.177
HWC20T2	0.85	0.07	37	36.6	8.8	5.9	39.2	19.51	106	0.103
HWC20T3	1.38	0.06	35	38.2	10.9	4.8	67.5	18.62	129	0.194
HWC20T4	1.34	0.05	39	38.7	6.2	8.3	33.1	16.44	95	0.348
HWC20T4X	1.36	0.05	39	39.1	14.0	9.3	36.8	15.63	119	0.245
HWC21T1	1.41	0.07	42	36.0	10.7	7.3	53.1	13.92	51	0.402
HWC21T2	0.96	0.08	38	40.0	13.7	5.6	66.7	22.44	99	0.138
HWC21T3	1.23	0.05	39	24.8	6.6	5.5	48.1	7.97	89	0.161
HWC21T4	0.90	0.09	56	43.3	7.5	15.0	67.3	24.68	120	0.262
HWC23T1	1.19	0.07	33	37.6	10.3	4.5	50.3	10.92	62	0.118
HWC23T1X	0.58	0.08	39	38.1	12.6	10.0	61.1	16.01	96	0.099
HWC23T2	1.51	0.06	36	34.9	8.1	6.4	67.6	19.38	126	0.181
HWC23T2X	1.74	0.07	29	38.7	8.0	5.6	64.0	16.88	113	0.220

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Sc ppm	Se ppm	Sn ppm	Sr ppm	Th ppm	U ppm	V ppm	Y ppm	Yb ppm	Zn ppm
				Sandstones-continued						
HWC20S1	6.5	0.1L	0.7	191	5.2	1.7	38	8.2	0.85	49
HWC20S1X	7.0	0.1L	1.1	221	5.5	1.6	41	9.0	0.75	47
HWC20S2	4.7	0.1	0.8	177	5.1	2.1	43	10.2	1.26	54
HWC20S2X	4.3	0.1L	0.9	133	5.7	1.9	37	9.3	1.01	55
HWC20S3	9.7	0.1L	0.7	292	7.3	2.3	80	17.4	2.45	72
HWC20S3X	8.9	0.1L	0.1	272	9.4	2.3	80	16.8	2.35	74
HWC20S4	6.7	0.1	0.7	221	5.9	1.7	57	10.4	1.70	67
HWC21S1	9.6	0.1L	1.4	241	6.8	3.2	76	16.6	2.12	73
HWC21S1X	8.3	0.1L	1.1	262	8.6	3.1	69	21.5	2.98	74
HWC21S2	7.6	0.1	0.9	262	6.1	1.6	62	18.5	2.15	64
HWC21S3	6.5	0.3	0.2	273	7.0	1.5	54	15.0	1.64	61
HWC21S4	12.5	0.1L	0.7	213	5.8	2.1	77	17.8	2.23	78
HWC23S1	10.4	0.1L	1.1	258	8.0	3.1	88	20.9	2.72	96
HWC23S1X	14.5	0.1	0.8	317	12.6	2.6	106	28.0	3.29	97
HWC23S2	8.1	0.1L	1.3	216	8.1	2.3	64	13.0	1.92	70
HWC23S3	7.0	0.1	0.4	230	3.4	1.8	42	10.6	1.11	42
HWC23S3X	4.1	0.1L	0.3	231	5.7	1.8	36	8.0	0.75	40
HWC23S4	3.9	0.1L	0.6	178	3.4	1.6	33	23.7	3.44	33
HWC23S4X	6.0	0.1L	0.8	219	3.5	1.7	39	10.1	0.68	34
HWC27S1	3.3	0.1L	0.8	389	7.2	3.0	35	16.1	2.07	30
HWC27S2	10.2	0.1L	1.6	260	9.1	3.4	91	19.6	2.80	75
HWC27S3	10.8	0.2	0.8	278	8.6	2.1	96	16.1	2.39	67
HWC27S3X	10.4	0.1L	1.3	285	4.6	2.6	104	17.5	2.47	67
HWC27S4	3.4	0.1L	0.9	267	7.2	2.8	70	18.8	2.45	80
				Siltstones and shales-continued						
HWC20T1	18.6	0.8	1.3	244	10.7	3.3	140	20.5	3.36	115
HWC20T1X	16.0	0.2	1.4	304	11.3	3.4	112	24.4	3.77	114
HWC20T2	22.3	0.4	1.8	223	8.1	3.2	150	25.0	3.07	107
HWC20T3	17.0	0.2	2.0	239	11.8	3.1	138	23.4	3.51	127
HWC20T4	9.7	0.1L	2.1	230	12.1	5.6	101	16.8	2.62	107
HWC20T4X	9.2	0.1L	2.2	263	11.1	5.7	134	19.8	3.25	115
HWC21T1	21.6	0.4	2.1	243	10.2	3.7	140	25.9	3.84	107
HWC21T2	26.5	0.4	1.1	253	14.2	3.2	142	26.9	4.36	118
HWC21T3	14.3	0.2	1.5	277	11.4	3.1	106	25.7	3.26	95
HWC21T4	16.5	0.6	1.2	330	10.8	5.2	177	27.9	4.52	119
HWC23T1	16.0	0.2	2.2	189	14.6	7.8	118	23.6	3.38	115
HWC23T1X	21.2	0.3	0.6	225	10.9	3.8	152	29.4	4.01	116
HWC23T2	23.2	0.3	1.3	233	9.7	4.5	186	20.6	3.29	146
HWC23T2X	18.2	0.3	2.0	222	9.6	4.6	154	18.1	2.73	141

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Zr ppm	Total C%	Orgnc C%	Crbnt C%	Ash %	pH	Quartz	Oligclas	Micrclin	LayerSil
Sandstones-continued										
HWC20S1	119	4.69	0.03	4.66	94.5	9.3	23.57	8.27	0.00	21.25
HWC20S1X	119	4.87	0.40	4.47	98.4	9.4	26.34	10.25	0.00	22.03
HWC20S2	199	4.52	0.22	4.30	97.6	9.4	26.49	7.61	2.77	21.23
HWC20S2X	144	4.48	0.59	3.89	97.6	9.2	28.85	4.30	0.00	22.89
HWC20S3	186	1.22	0.66	0.56	96.6	8.7	40.90	12.75	0.00	36.90
HWC20S3X	306	1.15	0.46	0.69	95.5	8.4	39.50	15.22	0.00	39.03
HWC20S4	98	1.11	0.58	0.53	93.2	7.0	33.85	5.19	15.98	26.99
HWC21S1	238	1.25	0.48	0.77	96.6	9.3	43.25	8.71	0.00	41.40
HWC21S1X	377	1.25	0.67	0.58	97.5	9.2	48.33	17.60	0.00	25.81
HWC21S2	217	2.39	2.09	0.30	94.5	8.2	49.30	12.71	10.33	24.43
HWC21S3	135	0.75	0.40	0.35	97.2	8.8	55.26	7.23	10.60	24.31
HWC21S4	249	3.27	2.40	0.87	92.3	8.4	49.00	9.92	9.87	21.96
HWC23S1	262	1.88	0.66	1.22	96.4	8.5	31.61	11.26	2.65	40.82
HWC23S1X	283	1.83	0.80	1.03	95.6	8.5	32.26	8.05	5.23	44.05
HWC23S2	201	1.19	0.40	0.79	96.4	8.8	41.95	9.14	5.92	36.44
HWC23S3	149	5.28	0.03	5.25	98.0	9.5	22.92	9.00	3.61	15.09
HWC23S3X	138	5.54	0.32	5.22	97.9	9.3	23.98	8.64	0.00	16.79
HWC23S4	85	6.35	0.30	6.05	98.4	10.0	25.07	12.06	1.94	14.48
HWC23S4X	245	6.30	0.26	6.04	98.1	9.7	22.52	8.54	2.43	10.92
HWC27S1	256	0.38	0.25	0.13	98.0	8.7	70.91	5.84	7.60	14.70
HWC27S2	428	1.38	0.50	0.88	96.8	9.1	41.26	10.24	5.92	34.55
HWC27S3	207	1.51	0.39	1.12	95.4	9.3	37.87	10.03	5.25	38.73
HWC27S3X	224	1.53	0.67	0.86	95.5	9.1	38.09	7.65	3.33	38.11
HWC27S4	206	1.50	0.65	0.85	95.8	9.0	40.23	9.94	4.52	38.10
Siltstones and shales-continued										
HWC20T1	217	0.98	0.63	0.35	95.8	8.3	33.98	13.99	0.00	49.25
HWC20T1X	257	0.94	0.94	0.01L	94.4	8.5	37.17	8.17	6.04	46.40
HWC20T2	173	2.07	0.67	1.40	93.8	8.3	26.55	7.08	3.60	50.66
HWC20T3	140	1.44	1.02	0.42	95.5	7.9	23.97	8.78	0.00	57.77
HWC20T4	309	0.69	0.69	0.01L	94.5	5.1	39.36	1.95	5.99	50.40
HWC20T4X	272	0.68	0.68	0.01L	95.3	5.8	39.06	0.00	6.97	48.33
HWC21T1	240	1.92	1.05	0.87	94.7	8.8	28.32	11.86	0.00	54.32
HWC21T2	202	2.06	1.05	1.01	93.1	8.6	27.29	10.24	0.00	61.33
HWC21T3	322	2.16	1.18	0.98	95.4	8.9	34.97	12.86	0.00	43.59
HWC21T4	299	0.71	0.71	0.01L	94.2	8.4	29.70	2.27	0.00	65.53
HWC23T1	189	2.48	0.92	1.56	94.1	8.1	29.91	8.82	0.00	50.41
HWC23T1X	280	2.34	0.76	1.58	95.3	8.3	32.24	6.86	3.34	48.20
HWC23T2	227	1.35	1.35	0.01L	96.9	7.5	26.98	9.49	0.00	60.14
HWC23T2X	198	1.39	1.39	0.01L	94.3	7.5	27.11	9.60	0.00	59.20

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Calcite	Mg-Calc	Dolomite	Ca-Dolo	Siderite	Ca-Sider	Pyrite	Marcasit	Gypsum	Smectite
				Sandstones-continued						
HWC20S1	19.14	0.00	0.00	27.76	0.00	0.00	0.00	0.00	0.00	10.63
HWC20S1x	16.36	0.00	0.00	25.02	0.00	0.00	0.00	0.00	0.00	15.42
HWC20S2	1.34	0.00	0.00	40.56	0.00	0.00	0.00	0.00	0.00	11.68
HWC20S2x	1.91	0.00	0.00	41.80	0.25	0.00	0.00	0.00	0.00	16.02
HWC20S3	0.00	0.87	7.07	0.00	0.78	0.74	0.00	0.00	0.00	12.92
HWC20S3x	0.91	0.00	2.92	0.00	0.00	2.43	0.00	0.00	0.00	19.52
HWC20S4	0.00	0.00	3.54	0.00	0.00	0.96	3.49	9.99	0.00	1.35
HWC21S1	2.39	0.00	4.25	0.00	0.00	0.00	0.00	0.00	0.00	14.49
HWC21S1x	2.49	0.00	5.39	0.00	0.00	0.38	0.00	0.00	0.00	12.91
HWC21S2	0.00	0.00	1.17	0.00	2.07	0.00	0.00	0.00	0.00	1.22
HWC21S3	0.00	0.00	0.00	0.91	0.00	1.68	0.00	0.00	0.00	3.65
HWC21S4	0.00	0.00	0.00	1.08	0.00	8.18	0.00	0.00	0.00	2.20
HWC23S1	3.35	0.00	4.16	0.00	0.27	0.00	0.00	0.00	5.87	12.24
HWC23S1x	3.45	0.00	0.00	6.96	0.00	0.00	0.00	0.00	0.00	19.82
HWC23S2	2.21	0.00	4.34	0.00	0.00	0.00	0.00	0.00	0.00	12.75
HWC23S3	0.00	0.00	0.00	49.04	0.34	0.00	0.00	0.00	0.00	9.05
HWC23S3x	0.00	0.00	0.00	50.29	0.00	0.30	0.00	0.00	0.00	9.23
HWC23S4	0.00	0.00	0.00	46.16	0.00	0.28	0.00	0.00	0.00	8.69
HWC23S4x	0.00	0.00	0.00	55.58	0.00	0.00	0.00	0.00	0.00	6.55
HWC27S1	0.00	0.00	0.00	0.35	0.60	0.00	0.00	0.00	0.00	1.48
HWC27S2	0.76	0.00	6.20	0.00	1.07	0.00	0.00	0.00	0.00	20.73
HWC27S3	1.20	0.00	3.66	0.00	0.53	2.73	0.00	0.00	0.00	30.98
HWC27S3x	2.19	0.00	6.42	0.00	1.31	2.90	0.00	0.00	0.00	26.68
HWC27S4	2.94	0.00	3.55	0.00	0.00	0.70	0.00	0.00	0.00	22.86
				Siltstones and shales-continued						
HWC20T1	0.00	0.00	2.35	0.00	0.43	0.00	0.00	0.00	0.00	22.16
HWC20T1x	0.00	0.00	1.44	0.00	0.00	0.78	0.00	0.00	0.00	11.60
HWC20T2	0.00	1.28	3.00	0.00	1.46	6.38	0.00	0.00	0.00	5.06
HWC20T3	0.99	0.00	2.26	2.56	0.00	0.97	2.70	0.00	0.00	11.55
HWC20T4	0.00	0.00	0.00	0.00	0.00	0.00	2.30	0.00	0.00	17.64
HWC20T4x	0.00	1.43	0.00	1.87	0.00	0.00	2.34	0.00	0.00	19.33
HWC21T1	1.47	0.00	3.23	0.00	0.80	0.00	0.00	0.00	0.00	10.86
HWC21T2	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.13
HWC21T3	3.65	0.00	4.60	0.00	0.33	0.00	0.00	0.00	0.00	13.08
HWC21T4	0.00	0.00	0.00	0.61	0.00	0.00	1.90	0.00	0.00	36.04
HWC23T1	3.39	0.00	3.85	0.00	0.32	3.29	0.00	0.00	0.00	7.56
HWC23T1x	3.66	0.00	4.46	0.00	1.23	0.00	0.00	0.00	0.00	4.82
HWC23T2	0.00	0.00	0.00	0.10	0.77	0.00	2.51	0.00	0.00	21.05
HWC23T2x	0.00	0.00	0.00	0.00	0.76	0.00	3.33	0.00	0.00	14.80

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Illite	Chlorite	Kaolinit
			Sandstones-continued
HWC20S1	3.19	4.25	3.19
HWC20S1X	2.20	2.20	2.20
HWC20S2	3.18	3.18	3.18
HWC20S2X	2.29	2.29	2.29
HWC20S3	3.69	5.54	14.76
HWC20S3X	3.90	5.85	9.76
HWC20S4	1.35	1.35	22.94
HWC21S1	4.14	8.28	14.49
HWC21S1X	5.16	6.45	1.29
HWC21S2	1.22	1.22	20.77
HWC21S3	1.22	1.22	18.23
HWC21S4	1.10	1.10	17.57
HWC23S1	8.16	10.20	10.20
HWC23S1X	4.40	6.61	13.22
HWC23S2	5.47	5.47	12.75
HWC23S3	2.26	2.26	1.51
HWC23S3X	2.51	2.51	2.51
HWC23S4	2.90	2.17	0.72
HWC23S4X	2.18	2.18	0.00
HWC27S1	1.48	0.74	11.03
HWC27S2	1.73	3.46	8.64
HWC27S3	1.94	3.87	1.94
HWC27S3X	3.81	5.72	1.91
HWC27S4	1.91	2.82	9.53
			Siltstones and shales-continued
HWC20T1	7.39	9.85	9.85
HWC20T1X	11.60	11.60	11.60
HWC20T2	22.79	20.26	2.53
HWC20T3	23.11	17.33	5.78
HWC20T4	7.56	5.04	20.16
HWC20T4X	7.25	4.83	16.92
HWC21T1	19.01	19.01	5.43
HWC21T2	24.53	24.53	6.13
HWC21T3	6.54	8.72	15.26
HWC21T4	9.83	6.55	13.11
HWC23T1	12.60	15.12	15.12
HWC23T1X	19.28	16.87	7.23
HWC23T2	18.04	18.04	3.01
HWC23T2X	23.68	20.72	0.00

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Si %	Al %	Ca %	Mg %	Na %	K %	Fe %	Ti %	Mn %	Ag ppm
				Siltstones and shales-continued						
HWC23T3	30	5.5	4.03	1.47	0.99	1.82	2.11	0.36	0.045	0.15
HWC23T4	26	7.2	4.17	1.47	0.83	2.49	3.77	0.43	0.075	0.50
HWC27T1	30	8.2	0.50	0.69	0.12	2.21	1.96	0.44	0.026	0.28
HWC27T1X	31	7.9	0.44	0.70	0.15	2.25	2.08	0.43	0.025	0.32
HWC27T2	27	8.7	0.65	0.74	0.37	2.09	2.44	0.44	0.026	0.29
HWC27T2X	31	8.6	0.67	0.75	0.36	2.19	2.23	0.45	0.038	0.31
HWC27T3	30	5.5	4.04	1.56	0.93	1.96	1.96	0.36	0.057	0.43
HWC27T3X	29	5.8	4.02	1.60	0.92	1.95	1.99	0.35	0.047	0.40
HWC27T4	27	6.3	5.83	1.73	0.88	2.05	2.71	0.38	0.073	0.35
HWC27T4X	27	6.1	5.72	1.70	0.88	2.08	2.64	0.37	0.060	0.44
				Dark shales						
HWC20H1	28	7.9	1.25	1.05	0.38	2.42	2.82	0.39	0.040	0.36
HWC20H2	28	7.8	1.13	0.89	0.46	2.29	2.85	0.43	0.087	0.37
HWC20H3	27	7.8	1.31	1.03	0.58	2.20	2.47	0.42	0.050	0.44
HWC20H4	25	8.3	1.49	1.29	0.56	2.63	4.07	0.42	0.101	0.48
HWC20H4X	26	8.6	1.49	1.28	0.57	2.71	4.12	0.44	0.108	0.14
HWC21H1	23	7.2	0.70	0.82	0.58	2.14	3.35	0.34	0.022	0.30
HWC21H1X	24	7.5	0.72	0.82	0.60	2.32	3.43	0.34	0.022	0.12
HWC21H2	25	7.2	1.34	1.21	0.78	2.48	2.58	0.42	0.023	0.54
HWC21H2X	26	7.2	1.27	1.17	0.79	2.42	2.58	0.39	0.046	0.44
HWC21H3	26	8.4	1.17	1.29	0.77	2.66	2.58	0.44	0.025	0.48
HWC21H3X	26	9.0	1.12	1.26	0.75	2.67	2.54	0.46	0.025	0.38
HWC21H4	20	6.6	0.76	0.48	0.45	1.09	1.44	0.41	0.018	0.36
HWC23H1	28	7.3	1.48	0.96	0.51	2.33	2.45	0.38	0.025	0.37
HWC23H2	27	6.4	4.37	0.88	0.58	1.85	2.71	0.38	0.059	0.47
HWC23H2X	27	7.6	1.09	0.87	0.54	2.36	3.19	0.42	0.113	0.47
HWC23H3	26	9.0	1.43	1.24	0.60	2.63	3.36	0.44	0.083	0.43
HWC23H3X	26	9.1	1.41	1.18	0.58	2.65	3.37	0.46	0.080	0.42
HWC23H4	23	7.5	0.88	0.85	0.51	2.33	2.13	0.40	0.021	0.42
HWC23H4X	23	8.2	0.87	0.87	0.52	2.34	2.04	0.42	0.021	0.12
HWC27H1	23	9.7	0.91	0.80	0.18	1.52	2.73	0.43	0.022	0.38
HWC27H2	27	7.7	1.57	1.01	0.51	2.23	4.99	0.41	0.168	0.37
HWC27H3	28	8.0	1.20	0.55	0.59	2.35	2.58	0.45	0.025	0.42
HWC27H4	18	6.1	0.89	0.58	0.45	1.40	1.47	0.34	0.016	0.32
				Special samples						
HWC20D1	15	4.2	2.68	2.65	0.31	1.40	18.07	0.23	0.270	0.13
HWC20D2	21	6.5	0.72	0.86	0.37	1.95	4.24	0.30	0.020	0.11

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	As ppm	B ppm	Ba ppm	Be ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	F ppm	Ga ppm
				Siltstones and shales-continued						
HWC23T3	4.2	46	618	1.84	59	10.9	83	67.6	600	18.6
HWC23T4	2.7	59	513	2.98	41	11.6	92	40.7	800	21.1
HWC27T1	11.4	70	361	3.22	37	16.2	94	25.5	600	20.8
HWC27T1X	4.4	64	457	3.12	115	18.9	100	27.1	800	26.6
HWC27T2	6.2	63	359	3.55	65	9.8	92	38.9	1000	22.9
HWC27T2X	4.9	62	423	3.48	90	11.4	100	53.3	700	24.3
HWC27T3	5.3	44	473	1.71	64	10.3	69	30.5	700	16.9
HWC27T3X	4.7	46	421	1.70	52	10.2	68	18.7	700	16.5
HWC27T4	4.3	57	544	2.21	102	12.2	90	40.9	700	20.7
HWC27T4X	5.9	51	535	1.93	72	13.2	95	59.9	800	22.3
				Dark shales-continued						
HWC20H1	4.7	70	314	3.47	167	12.8	110	57.7	900	24.9
HWC20H2	13.6	62	374	3.11	0 B	15.7	97	47.1	800	20.7
HWC20H3	8.1	71	485	3.09	70	16.2	103	74.5	800	24.2
HWC20H4	8.6	77	529	3.55	81	18.4	118	63.7	500	28.5
HWC20H4X	4.4	68	521	3.07	56	18.5	104	0.0B	800	30.7
HWC21H1	12.9	62	374	3.13	83	16.0	96	48.8	900	27.8
HWC21H1X	1.7	64	570	3.58	150	17.4	105	18.2	900	24.6
HWC21H2	9.9	65	581	3.21	75	20.9	126	72.2	800	29.8
HWC21H2X	10.4	56	655	3.27	102	20.4	118	73.7	800	24.7
HWC21H3	4.0	74	585	3.01	45	19.0	118	69.5	1000	24.9
HWC21H3X	5.5	62	541	2.48	45	16.3	101	47.1	1100	26.5
HWC21H4	5.1	51	371	2.31	88	12.2	252	39.0	500	17.4
HWC23H1	4.1	62	335	3.19	155	11.8	95	42.3	800	26.5
HWC23H2	24.7	66	494	3.74	119	17.4	105	56.3	600	23.4
HWC23H2X	27.4	64	424	3.66	106	17.5	105	93.6	800	27.7
HWC23H3	6.4	67	513	2.11	44	16.7	110	88.1	1000	28.7
HWC23H3X	6.2	73	464	2.95	52	18.4	112	74.1	900	30.2
HWC23H4	4.7	60	419	3.18	47	19.4	115	48.4	800	32.3
HWC23H4X	11.9	67	636	3.96	89	20.7	121	54.5	800	35.9
HWC27H1	12.6	62	240	5.05	83	11.8	99	68.2	900	28.2
HWC27H2	6.2	64	368	3.73	81	17.8	101	25.4	800	24.2
HWC27H3	7.3	61	455	2.89	85	15.0	102	53.6	1000	25.8
HWC27H4	10.0	50	459	3.35	53	13.1	66	46.8	600	21.4
				Special samples-continued						
HWC2001	2.7	68	346	3.87	70	9.5	96	64.8	600	20.8
HWC2002	21.2	59	214	4.50	45	19.5	81	63.8	900	25.7

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Ge ppm	Hg ppm	La ppm	Li ppm	Mo ppm	Nb ppm	Ni ppm	Pb ppm	Rb ppm	Total S%
				Siltstones and shales-continued						
HWC23T3	1.22	0.04	38	20.1	8.9	8.2	36.5	9.18	60	0.054
HWC23T4	0.93	0.06	34	40.2	10.2	8.2	42.9	13.93	74	0.118
HWC27T1	1.54	0.05	43	56.3	5.7	13.4	47.2	12.80	63	0.361
HWC27T1X	1.45	0.05	51	49.8	8.6	10.4	50.9	15.96	95	0.271
HWC27T2	1.10	0.06	38	52.8	7.9	13.2	35.6	16.88	123	0.231
HWC27T2X	0.97	0.06	55	50.9	11.5	17.9	40.5	15.65	111	0.228
HWC27T3	0.60	0.06	36	22.0	6.9	6.4	41.3	6.00	80	0.131
HWC27T3X	0.75	0.08	33	26.8	5.2	4.3	35.0	7.18	81	0.153
HWC27T4	1.11	0.07	38	24.0	7.9	9.9	49.5	11.72	94	0.179
HWC27T4X	1.19	0.06	39	27.1	6.9	7.2	52.6	8.26	77	0.086
				Dark shales-continued						
HWC20H1	1.34	0.07	50	48.2	8.5	12.8	48.7	16.63	135	0.395
HWC20H2	1.75	0.10	42	41.9	9.1	8.7	57.5	19.75	58	0.373
HWC20H3	1.36	0.10	42	39.0	12.3	14.3	51.6	17.98	112	0.296
HWC20H4	1.53	0.13	42	34.7	12.2	6.4	71.1	21.42	116	0.270
HWC20H4X	1.38	0.12	35	44.6	11.8	4.6	60.1	22.63	101	0.266
HWC21H1	0.94	0.05	47	36.8	10.6	5.9	51.8	23.52	89	0.525
HWC21H1X	0.53	0.04	49	33.2	9.7	7.3	56.7	19.68	112	0.442
HWC21H2	1.90	0.16	44	44.5	10.2	6.1	74.2	23.17	113	0.380
HWC21H2X	2.15	0.15	47	34.3	7.9	4.6	74.5	24.62	82	0.349
HWC21H3	1.57	0.09	42	46.3	8.5	9.9	73.6	20.41	119	0.182
HWC21H3X	1.05	0.10	29	43.7	6.9	3.7	59.6	20.66	119	0.201
HWC21H4	0.75	0.31	43	31.8	4.1	8.7	37.1	18.47	68	0.379
HWC23H1	2.10	0.07	44	44.5	7.3	11.7	42.5	19.54	134	0.288
HWC23H2	1.64	0.08	53	36.8	7.2	12.7	56.1	22.42	118	0.172
HWC23H2X	1.36	0.09	53	49.6	12.1	8.9	55.6	24.69	128	0.422
HWC23H3	1.11	0.09	36	40.9	12.0	4.2	67.9	20.91	63	0.326
HWC23H3X	1.17	0.09	38	39.2	12.1	5.1	70.7	23.70	50	0.274
HWC23H4	2.09	0.28	39	48.4	8.7	3.2	70.4	22.81	103	0.271
HWC23H4X	0.77	0.26	39	33.5	1.1	9.6	77.8	26.69	93	0.294
HWC27H1	0.93	0.17	59	57.0	19.4	9.8	51.6	39.57	33	0.370
HWC27H2	1.28	0.07	52	40.5	13.2	18.3	49.8	22.30	62	0.330
HWC27H3	0.85	0.10	53	47.6	8.1	11.3	51.4	20.40	95	0.356
HWC27H4	2.49	0.44	39	33.4	5.2	4.7	59.0	19.67	52	0.372
				Special samples-continued						
HWC2001	0.60	0.06	28	21.4	3.6	6.6	29.0	19.86	67	0.207
HWC2002	8.12	0.17	33	36.6	13.4	5.6	81.3	19.10	99	0.525

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Sc ppm	Se ppm	Sn ppm	Sr ppm	Th ppm	U ppm	V ppm	Y ppm	Yb ppm	Zn ppm
Siltstones and shales-continued										
HWC23T3	14.4	0.2	2.1	277	9.6	3.1	98	28.2	3.48	86
HWC23T4	15.0	0.4	0.6	272	10.0	3.1	116	20.8	3.21	114
HWC27T1	13.1	0.1	2.0	241	17.9	7.5	150	22.9	3.51	116
HWC27T1X	17.5	0.6	2.3	267	21.7	6.8	184	32.7	4.31	132
HWC27T2	12.8	0.1L	1.2	224	15.2	6.0	165	28.6	4.14	113
HWC27T2X	16.4	0.2	1.5	221	15.3	5.7	156	28.2	4.36	105
HWC27T3	10.2	0.4	0.2	261	10.1	3.3	85	19.6	2.59	86
HWC27T3X	9.5	0.1L	0.6	239	11.1	3.0	86	17.6	2.45	89
HWC27T4	15.5	0.1L	1.4	278	15.0	2.9	116	23.9	3.37	90
HWC27T4X	17.5	0.2	2.0	269	7.2	3.3	112	28.6	3.44	94
Dark shales-continued										
HWC20H1	16.5	0.3	1.8	250	17.0	3.9	157	26.8	4.19	107
HWC20H2	17.9	0.2	2.2	272	13.8	3.9	136	27.2	4.03	143
HWC20H3	16.5	0.2	2.1	237	13.2	4.4	160	28.1	3.63	133
HWC20H4	22.7	0.3	1.6	204	13.5	3.5	157	27.6	4.10	141
HWC20H4X	23.1	0.5	2.4	184	10.5	3.9	151	28.1	4.17	139
HWC21H1	15.9	0.5	1.7	276	10.3	5.7	131	22.2	3.51	111
HWC21H1X	21.3	0.1L	0.4	315	9.6	5.5	162	40.7	3.99	115
HWC21H2	23.4	0.6	1.0	251	13.8	3.7	168	25.6	4.24	139
HWC21H2X	24.4	0.5	0.8	246	11.7	4.0	178	29.6	4.09	138
HWC21H3	21.4	0.5	2.3	229	11.1	3.8	171	28.8	4.04	137
HWC21H3X	18.6	0.1L	1.3	198	13.5	3.5	147	25.1	3.39	137
HWC21H4	12.8	0.4	0.8	273	23.1	7.0	121	26.7	3.51	100
HWC23H1	16.9	0.5	1.4	272	13.1	4.2	145	24.5	3.63	111
HWC23H2	18.4	0.7	2.1	306	14.2	3.8	157	33.7	4.49	134
HWC23H2X	17.9	0.4	1.6	297	16.2	3.9	162	30.6	4.59	133
HWC23H3	19.7	0.5	1.9	185	13.1	3.6	134	23.9	3.78	140
HWC23H3X	19.8	0.1L	2.2	193	12.7	3.9	122	22.9	3.90	138
HWC23H4	22.7	1.0	0.4	230	15.3	4.5	152	22.4	3.87	119
HWC23H4X	23.9	0.2	1.1	267	15.6	4.6	156	31.5	4.77	118
HWC27H1	15.2	1.0	1.2	282	23.0	11.4	192	32.0	4.72	133
HWC27H2	19.4	0.4	2.4	250	13.0	3.9	105	30.7	4.08	125
HWC27H3	20.1	0.3	0.7	254	17.1	3.9	145	30.6	4.16	135
HWC27H4	17.2	0.2	1.0	249	16.9	7.1	118	35.7	3.61	80
Special samples-continued										
HWC2001	14.5	0.3	0.1	165	9.8	2.2	90	28.5	3.63	94
HWC2002	17.9	0.3	1.2	247	12.0	9.6	187	21.0	3.27	118

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Zr ppm	Total C%	Orgnc C%	Crbnt C%	Ash %	pH	Quartz	Oligclas	Micrclin	LayerSil
				Siltstones and shales-continued						
HWC23T3	327	1.91	0.91	1.00	95.9	8.9	39.55	14.13	0.00	38.32
HWC23T4	219	1.93	0.55	1.38	98.1	8.8	30.75	10.70	0.00	48.75
HWC27T1	235	0.76	0.76	0.01L	95.5	7.0	36.88	0.00	2.21	59.32
HWC27T1x	318	0.75	0.68	0.07	93.9	6.9	36.16	0.00	4.27	57.96
HWC27T2	286	0.96	0.75	0.21	94.3	8.2	36.21	3.34	3.75	54.63
HWC27T2X	286	0.93	0.86	0.07	96.0	7.9	32.06	2.67	2.45	61.49
HWC27T3	300	1.84	0.70	1.14	95.8	9.1	36.50	7.70	4.27	43.43
HWC27T3x	254	1.74	0.66	1.08	95.8	9.1	34.10	8.46	3.71	44.23
HWC27T4	233	2.41	0.84	1.57	96.1	9.1	31.91	9.37	2.24	43.20
HWC27T4X	306	2.36	1.25	1.11	96.8	8.9	31.88	8.57	3.66	44.31
				Dark shales-continued						
HWC20H1	272	2.90	2.62	0.28	90.9	7.7	28.39	1.66	4.36	60.78
HWC20H2	251	2.74	2.53	0.21	91.0	8.1	27.89	5.71	0.00	60.65
HWC20H3	233	3.08	2.72	0.36	90.8	8.0	30.57	7.20	0.00	53.66
HWC20H4	156	4.84	4.33	0.51	88.9	8.2	26.74	6.72	0.00	60.24
HWC20H4X	172	4.80	4.80	0.01L	89.1	7.8	26.58	5.44	3.38	56.92
HWC21H1	185	9.58	9.51	0.07	80.0	5.4	22.91	2.02	0.00	68.36
HWC21H1x	265	9.15	9.15	0.01L	81.0	5.7	23.18	2.47	0.00	67.22
HWC21H2	298	7.42	7.15	0.27	85.5	7.7	28.24	10.01	0.00	56.67
HWC21H2x	284	8.01	7.94	0.07	85.8	7.7	29.97	10.22	0.00	55.31
HWC21H3	219	4.54	4.40	0.14	90.7	7.9	26.69	6.84	3.27	59.51
HWC21H3x	156	4.45	0.18	0.27	91.0	7.8	29.18	7.83	2.27	55.70
HWC21H4	229	21.16	21.16	0.01L	66.2	6.8	31.69	2.39	0.00	61.31
HWC23H1	273	4.40	3.98	0.42	90.9	7.9	31.47	2.69	0.00	60.37
HWC23H2	276	2.67	2.60	0.07	91.9	8.4	29.91	2.79	4.02	56.67
HWC23H2x	242	2.54	2.12	0.42	91.8	8.4	29.54	2.32	6.87	56.41
HWC23H3	142	4.51	4.16	0.35	89.0	8.2	27.05	7.60	0.00	60.34
HWC23H3x	159	4.51	4.23	0.28	89.1	8.0	26.35	7.36	0.00	60.94
HWC23H4	201	11.87	11.87	0.01L	78.1	7.6	27.14	3.16	2.89	63.12
HWC23H4x	233	12.61	12.61	0.01L	77.8	7.7	25.34	3.64	2.23	66.57
HWC27H1	218	6.57	6.50	0.07	82.6	7.3	16.09	0.00	0.93	78.36
HWC27H2	229	3.25	2.48	0.77	89.9	8.4	29.80	1.42	5.93	53.80
HWC27H3	352	2.68	2.40	0.28	91.5	8.2	28.40	3.80	2.44	59.93
HWC27H4	175	24.89	24.89	0.01L	60.7	7.2	28.38	2.56	2.89	64.37
				Special samples-continued						
HWC2001	167	7.06	2.15	4.91	82.4	8.2	18.11	2.00	0.00	31.47
HWC2002	243	12.91	12.91	0.01L	74.6	4.2	18.34	1.01	4.03	67.30

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Calcite	Mg-Calc	Dolomite	Ca-Dolo	Siderite	Ca-Sider	Pyrite	Marcasit	Gypsum	Smectite
Siltstones and shales-continued										
HWC23T3	2.46	0.00	4.63	0.00	0.00	0.89	0.00	0.00	0.00	19.16
HWC23T4	2.94	0.00	3.63	0.00	0.65	2.58	0.00	0.00	0.00	7.31
HWC27T1	0.00	0.00	0.00	0.00	0.00	0.00	1.59	0.00	0.00	17.80
HWC27T1X	0.00	0.00	0.00	0.00	0.00	0.00	1.61	0.00	0.00	20.29
HWC27T2	0.00	0.00	0.00	0.00	0.60	0.00	1.48	0.00	0.00	21.85
HWC27T2X	0.00	0.00	0.00	0.00	0.00	0.00	1.32	0.00	0.00	27.67
HWC27T3	2.06	0.00	5.58	0.00	0.46	0.00	0.00	0.00	0.00	23.89
HWC27T3X	2.39	0.00	6.23	0.00	0.59	0.28	0.00	0.00	0.00	22.11
HWC27T4	5.54	0.00	5.22	0.00	1.40	1.12	0.00	0.00	0.00	15.12
HWC27T4X	5.23	0.00	5.42	0.00	0.93	0.00	0.00	0.00	0.00	19.94
Dark shales-continued										
HWC20H1	0.00	0.00	1.23	0.00	0.00	0.43	3.15	0.00	0.00	24.31
HWC20H2	0.00	0.00	1.27	0.00	0.00	1.17	3.32	0.00	0.00	15.16
HWC20H3	0.00	0.00	2.09	0.00	0.41	0.92	5.14	0.00	0.00	10.73
HWC20H4	0.00	0.00	1.64	0.00	0.00	4.65	0.00	0.00	0.00	0.00
HWC20H4X	0.00	0.00	1.77	0.00	0.00	3.65	2.25	0.00	0.00	2.84
HWC21H1	0.00	0.00	0.00	0.00	0.00	0.00	6.70	0.00	0.00	30.76
HWC21H1X	0.00	0.00	0.34	0.00	0.00	0.00	6.79	0.00	0.00	33.61
HWC21H2	0.00	0.00	1.84	0.00	0.00	0.40	2.85	0.00	0.00	2.83
HWC21H2X	0.00	0.00	1.89	0.00	0.29	0.88	1.45	0.00	0.00	5.53
HWC21H3	0.00	0.00	1.40	0.00	0.63	0.00	0.00	0.00	0.00	2.97
HWC21H3X	0.00	0.00	1.26	0.00	1.22	0.00	2.54	0.00	0.00	2.78
HWC21H4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.61	27.59
HWC23H1	0.78	0.00	1.53	0.00	0.00	0.79	2.38	0.00	0.00	30.19
HWC23H2	0.00	0.00	0.66	0.00	0.00	2.22	3.74	0.00	0.00	19.83
HWC23H2X	0.00	0.00	0.72	0.00	0.00	2.59	1.55	0.00	0.00	22.56
HWC23H3	0.00	0.00	1.67	0.00	0.00	2.58	0.76	0.00	0.00	3.02
HWC23H3X	0.00	0.00	1.84	0.00	0.00	2.36	1.14	0.00	0.00	0.00
HWC23H4	0.00	0.00	0.00	0.00	0.00	1.11	2.57	0.00	0.00	3.16
HWC23H4X	0.00	0.00	0.00	0.00	0.00	0.00	2.21	0.00	0.00	0.00
HWC27H1	0.00	0.00	0.00	0.00	0.00	0.00	4.61	0.00	0.00	35.26
HWC27H2	0.00	0.00	0.65	0.00	0.00	6.80	1.59	0.00	0.00	16.14
HWC27H3	0.00	0.00	1.17	0.00	0.26	0.22	3.78	0.00	0.00	24.00
HWC27H4	0.00	0.00	0.00	0.00	0.00	0.00	1.81	0.00	0.00	6.43
Special samples-continued										
HWC2001	0.00	0.00	2.15	0.00	0.00	46.27	0.00	0.00	0.00	9.44
HWC2002	0.00	0.00	0.00	0.00	0.00	0.00	9.32	0.00	0.00	33.65

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Illite	Chlorite	Kaolinit
Siltstones and shales-continued			
HWC23T3	3.83	3.83	7.66
HWC23T4	14.62	19.50	7.31
HWC27T1	5.93	2.97	32.63
HWC27T1X	8.69	2.90	26.08
HWC27T2	8.19	2.73	21.85
HWC27T2X	6.15	3.07	24.60
HWC27T3	6.51	6.51	6.51
HWC27T3X	6.63	6.63	8.85
HWC27T4	6.48	15.12	6.48
HWC27T4X	8.86	11.07	4.43
Dark shales-continued			
HWC20H1	12.15	3.04	21.27
HWC20H2	9.10	6.07	30.33
HWC20H3	13.41	8.04	26.83
HWC20H4	18.07	24.10	18.07
HWC20H4X	22.76	22.76	8.53
HWC21H1	10.25	6.85	10.25
HWC21H1X	13.44	6.72	13.44
HWC21H2	22.67	25.50	5.67
HWC21H2X	16.59	22.12	11.06
HWC21H3	26.78	26.78	2.97
HWC21H3X	25.06	25.06	2.78
HWC21H4	6.13	0.00	27.59
HWC23H1	12.07	6.04	12.07
HWC23H2	11.33	5.67	19.83
HWC23H2X	8.46	5.64	19.18
HWC23H3	15.09	21.12	21.12
HWC23H3X	24.38	24.38	12.19
HWC23H4	18.94	22.09	18.94
HWC23H4X	23.30	23.30	19.97
HWC27H1	7.84	3.92	31.34
HWC27H2	8.07	5.38	24.21
HWC27H3	9.00	3.00	24.00
HWC27H4	19.31	19.31	19.31
Special samples-continued			
HWC2001	6.29	4.72	11.01
HWC2002	13.46	6.73	13.46

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Si %	Al %	Ca %	Mg %	Na %	K %	Fe %	Ti %	Mn %	Ag ppm
				Special samples-continued						
HWC2003	25	8.2	0.80	0.64	0.43	1.85	1.67	0.45	0.021	0.33
HWC2004	10	3.1	23.30	1.29	0.34	1.17	6.47	0.22	0.113	0.56
HWC2005	28	5.5	4.93	1.62	0.84	1.80	2.71	0.36	0.070	0.33
HWC2101	34	4.9	0.83	0.82	1.07	1.67	2.56	0.30	0.064	0.15
HWC2102	30	8.0	0.74	1.11	0.95	2.73	2.42	0.46	0.026	0.56
HWC2103	19	6.9	0.70	0.65	0.55	1.81	4.51	0.29	0.020	0.27
HWC2104	16	2.6	22.31	1.27	0.53	1.23	3.19	0.19	0.082	0.99
HWC2105	27	6.9	4.53	1.60	0.88	2.32	3.98	0.41	0.086	0.62
HWC2301	27	7.3	0.52	0.46	0.68	2.18	2.53	0.40	0.022	0.59
HWC2302	34	5.3	1.35	0.71	0.83	2.09	1.79	0.29	0.040	0.29
HWC2303	14	4.2	2.79	2.78	0.34	1.40	17.84	0.24	0.237	0.12
HWC2501	10	2.6	25.23	1.36	0.35	1.18	4.79	0.21	0.089	0.98
HWC2502	33	5.8	2.26	1.26	1.00	1.86	1.67	0.33	0.059	0.15
HWC2503	27	5.8	4.42	1.44	0.88	1.96	2.58	0.40	0.067	0.52
HWC2504	13	4.5	0.70	0.58	0.35	1.12	4.82	0.19	0.015	0.16
HWC2505	12	3.6	2.99	2.50	0.27	1.30	19.84	0.19	0.331	0.12
HWC2506	28	7.9	3.06	1.47	0.57	2.64	1.95	0.45	0.041	0.48
HWC2507	25	5.9	5.18	1.56	0.60	2.17	2.49	0.36	0.068	0.34
HWC2508	21	7.8	0.81	0.66	0.29	1.48	3.14	0.37	0.020	0.50
HWC2509	30	5.6	2.80	1.16	0.59	2.11	1.96	0.36	0.065	0.42
HWC2510	34	5.7	1.45	0.66	0.79	2.21	1.58	0.32	0.026	0.36
HWC2511	26	8.6	0.82	0.70	0.34	2.36	4.19	0.43	0.101	0.52
HWC2512	32	5.6	2.39	1.42	0.41	2.44	1.03	0.34	0.027	0.15
HWC2701	28	5.3	5.15	2.04	0.65	2.44	3.05	0.34	0.096	0.37
HWC2702	10	4.7	0.88	0.45	0.14	0.73	7.11	0.21	0.013	0.18
HWC2703	35	5.1	0.54	0.47	0.62	2.05	1.55	0.36	0.039	0.38
HWC2704	30	7.6	1.09	1.28	0.92	2.62	2.65	0.41	0.026	0.45
HWC2705	15	3.9	19.22	1.61	0.55	1.32	3.52	0.27	0.060	0.53
HWC2706	28	5.7	4.29	1.61	0.93	1.98	2.99	0.38	0.055	0.36
HWC2707	23	4.0	14.37	1.44	0.76	1.29	2.06	0.27	0.048	0.30
HWC2708	17	5.5	0.75	0.64	0.53	1.49	5.74	0.26	0.018	0.28
HWC2709	34	5.3	2.13	1.13	0.70	1.92	1.48	0.31	0.026	0.27
HWC2710	33	4.7	3.04	1.26	0.62	1.98	1.75	0.33	0.026	0.15
HWC2711	31	5.2	3.35	1.22	0.61	2.05	1.85	0.31	0.038	0.31
HWC2712	30	6.1	3.10	1.18	0.55	2.06	2.00	0.37	0.067	0.37

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	As ppm	B ppm	Ba ppm	Be ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	F ppm	Ga ppm
				Special samples-continued						
HWC2003	11.3	65	381	2.89	38	13.3	80	77.8	800	22.5
HWC2004	5.7	18	557	1.69	49	4.4	37	21.8	600	8.3
HWC2005	3.8	52	380	1.84	89	9.3	83	44.0	700	18.1
HWC2101	4.5	27	542	1.85	97	13.9	62	10.0	400	15.9
HWC2102	23.0	59	725	2.91	78	15.4	117	74.0	900	27.5
HWC2103	57.2	58	477	4.20	73	13.8	68	69.0	700	24.1
HWC2104	2.8	13	679	1.14	102	6.1	56	15.9	400 L	9.6
HWC2105	3.1	53	530	3.18	107	13.1	110	93.4	800	25.8
HWC2301	10.4	77	900	2.04	66	15.2	99	92.5	600	18.1
HWC2302	5.5	34	363	1.48	35	10.9	70	13.0	500	12.5
HWC2303	4.3	64	263	3.84	60	7.2	89	44.3	900	19.9
HWC2501	8.9	16	788	1.53	71	6.0	51	26.4	500	11.9
HWC2502	1.6	26	359	1.27	80	12.3	41	9.1	600	12.6
HWC2503	4.6	50	481	2.31	80	13.5	99	67.8	600	20.3
HWC2504	10.9	52	151	4.40	62	8.4	51	79.6	600	18.8
HWC2505	7.4	67	252	4.37	41	7.0	103	51.7	600	20.7
HWC2506	7.8	50	504	1.49	94	26.8	126	64.9	1000	25.6
HWC2507	11.0	31	520	1.76	54	16.4	125	65.4	600	18.4
HWC2508	4.6	57	569	4.76	95	9.3	256	141.3	700	28.2
HWC2509	6.7	47	485	2.25	73	11.5	93	18.5	700	15.6
HWC2510	8.5	25	551	1.65	36	14.4	98	24.0	400 L	15.4
HWC2511	19.3	70	431	3.93	105	21.6	124	50.3	900	33.4
HWC2512	3.4	72	328	1.53	61	4.8	57	30.9	600	17.4
HWC2701	2.9	75	387	3.10	101	10.0	59	38.3	900	17.1
HWC2702	12.0	46	82	5.28	63	21.4	42	80.2	700	18.2
HWC2703	3.7	54	414	2.28	49	9.5	76	20.0	400	16.0
HWC2704	34.8	64	476	2.55	39	10.3	91	67.6	900	29.1
HWC2705	1.8	25	358	1.74	88	6.0	50	22.0	500	12.6
HWC2706	4.2	47	546	2.36	80	12.9	86	38.5	700	19.5
HWC2707	2.2	18	394	0.56	34	3.2	36	9.4	400	8.7
HWC2708	85.2	35	311	4.21	94	12.1	64	59.0	700	16.1
HWC2709	6.6	35	388	1.61	35	11.8	74	18.2	400	14.6
HWC2710	3.4	39	369	1.86	89	9.4	73	18.7	500	12.9
HWC2711	4.6	34	353	1.74	28	8.0	75	17.5	500	12.7
HWC2712	4.2	60	468	2.77	70	11.6	98	29.2	500	18.8

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Ge ppm	Hg ppm	La ppm	Li ppm	Mo ppm	Nb ppm	Ni ppm	Pb ppm	Rb ppm	Total S%
				Special samples-continued						
HWC2003	1.29	0.12	41	49.7	14.3	5.0	48.1	25.80	64	0.228
HWC2004	0.41	0.04	26	15.2	7.1	7.6	13.0	2.63	46	0.053
HWC2005	0.91	0.05	43	24.9	6.7	8.8	34.6	9.03	44	0.105
HWC2101	0.76	0.02	27	15.6	8.2	26.7	42.8	4.40	46	0.100
HWC2102	1.38	0.05	40	33.4	12.9	9.1	63.8	16.23	96	0.183
HWC2103	5.78	0.15	35	28.1	13.8	6.5	59.3	21.46	69	0.565
HWC2104	0.52	0.02	33	8.8	1.5	7.6	18.8	1.83	49	0.123
HWC2105	1.23	0.05	40	31.3	12.0	5.7	51.2	15.74	104	0.123
HWC2301	1.55	0.04	34	16.5	7.1	8.4	21.7	17.35	83	0.318
HWC2302	0.69	0.07	27	22.3	5.1	9.8	35.8	7.35	63	0.244
HWC2303	0.72	0.08	29	26.6	4.7	4.7	22.4	19.85	66	0.303
HWC2501	0.35	0.04	42	13.5	2.9	3.6	18.6	2.99	44	0.054
HWC2502	0.84	0.03	28	21.4	4.1	5.5	32.0	3.42	63	0.089
HWC2503	1.16	0.06	41	34.9	8.0	5.8	44.7	9.89	44	0.087
HWC2504	8.16	0.16	23	24.7	21.2	5.9	52.7	28.41	70	0.073
HWC2505	2.98	0.04	30	18.8	2.0	5.5	22.0	21.64	56	0.327
HWC2506	0.79	0.04	44	32.0	14.7	5.3	94.2	26.00	105	0.342
HWC2507	1.00	0.04	36	28.8	6.3	6.5	56.4	13.73	55	0.235
HWC2508	1.44	0.06	65	58.1	16.8	10.8	55.3	29.29	119	0.473
HWC2509	1.65	0.06	43	27.7	8.2	10.4	37.3	8.96	90	0.296
HWC2510	1.23	0.04	47	21.1	4.5	10.0	46.9	14.64	48	0.151
HWC2511	1.47	0.11	56	61.0	12.8	12.2	56.4	27.10	49	0.470
HWC2512	1.69	0.04	49	35.3	8.0	7.4	16.1	12.94	80	0.055
HWC2701	1.42	0.02	49	29.1	8.3	10.4	23.5	10.68	96	0.054
HWC2702	4.81	0.26	26	33.7	16.8	4.3	73.4	28.51	29	0.690
HWC2703	1.56	0.05	43	31.5	4.1	13.7	24.3	9.93	91	0.173
HWC2704	0.76	0.11	39	40.4	8.7	5.2	39.1	15.50	125	0.125
HWC2705	0.76	0.03	36	17.5	4.9	7.6	22.8	4.44	54	0.129
HWC2706	0.98	0.05	42	23.9	7.0	8.8	50.3	7.47	81	0.088
HWC2707	0.54	0.02	29	14.6	3.0	6.3	8.5	0.82	44	0.055
HWC2708	3.99	0.20	32	29.5	12.9	5.8	54.0	23.58	58	0.623
HWC2709	0.91	0.03	43	24.0	4.2	6.6	38.7	11.24	48	0.175
HWC2710	1.00	0.03	31	20.2	4.1	7.8	32.4	5.79	72	0.054
HWC2711	1.39	0.04	32	25.8	4.9	8.6	24.2	6.96	86	0.106
HWC2712	1.55	0.04	34	24.9	6.4	7.6	41.9	10.81	95	0.458

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Sc ppm	Se ppm	Sn ppm	Sr ppm	Th ppm	U ppm	V ppm	Y ppm	Yb ppm	Zn ppm
				Special samples-continued						
HWC2003	14.8	1.9	1.7	211	20.4	6.7	109	24.7	3.71	121
HWC2004	12.0	0.1L	0.3	287	0.08	2.0	40	14.4	1.16	59
HWC2005	12.7	0.1L	1.0	210	7.0	3.6	94	23.5	3.16	84
HWC2101	15.5	0.4	0.4	299	8.6	1.4	89	17.4	2.84	64
HWC2102	21.1	0.2	2.0	269	9.8	4.1	156	26.7	3.71	127
HWC2103	14.6	0.2	0.9	289	14.2	12.5	146	24.3	3.49	87
HWC2104	12.4	0.1L	0.4	384	5.3	1.4	37	14.3	1.53	44
HWC2105	20.6	0.4	1.6	310	9.5	3.3	149	31.2	4.02	108
HWC2301	19.9	0.1L	1.5	208	13.3	6.3	119	18.9	3.52	51
HWC2302	7.1	0.1L	0.5	200	4.9	3.2	61	13.5	2.03	64
HWC2303	10.7	0.5	0.3	157	8.9	2.4	80	20.0	3.42	82
HWC2501	17.0	0.1	0.4	317	3.9	1.5	52	13.7	1.21	56
HWC2502	6.3	0.1L	0.6	199	7.5	2.3	54	15.0	1.87	65
HWC2503	14.9	0.6	1.1	284	11.2	3.1	113	26.5	3.76	103
HWC2504	11.4	0.9	0.4	174	21.8	15.8	131	14.5	3.01	73
HWC2505	14.2	0.2	1.0	159	7.1	2.2	81	29.3	4.03	83
HWC2506	16.8	0.1L	0.9	298	10.5	3.7	141	30.0	4.09	132
HWC2507	14.3	0.4	1.4	262	8.2	2.5	98	23.0	3.14	94
HWC2508	23.6	0.3	0.8	321	21.2	24.3	263	34.3	5.35	91
HWC2509	11.9	0.1L	1.6	229	8.6	3.7	113	30.2	3.45	95
HWC2510	6.8	0.3	0.8	403	9.8	1.8	62	15.4	2.30	72
HWC2511	20.6	0.3	2.0	298	17.3	6.1	157	31.3	4.64	150
HWC2512	10.5	0.3	1.8	91	13.2	3.2	61	28.2	4.60	74
HWC2701	13.3	0.2	1.3	223	9.6	3.2	77	32.6	4.50	70
HWC2702	9.1	1.0	0.8	165	27.8	25.1	102	23.6	5.13	275
HWC2703	9.5	0.4	1.4	256	16.2	4.1	98	23.0	3.93	84
HWC2704	17.3	0.1L	1.1	178	9.0	3.6	124	21.1	3.30	114
HWC2705	13.4	0.1L	1.8	288	5.7	2.0	50	17.8	2.04	64
HWC2706	15.9	0.3	0.7	270	9.3	3.1	105	26.3	3.52	93
HWC2707	4.7	0.1L	0.7	286	5.8	2.0	35	11.1	1.18	52
HWC2708	11.7	0.9	0.8	234	14.0	12.7	126	16.8	2.65	62
HWC2709	7.1	0.1L	1.5	174	7.9	3.1	64	18.9	2.68	72
HWC2710	6.8	0.1L	0.1L	184	9.8	2.9	66	20.5	2.85	72
HWC2711	7.2	0.5	0.9	216	12.3	2.6	63	14.4	2.31	76
HWC2712	12.9	0.1L	1.9	228	14.8	3.7	124	25.1	3.59	87

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Zr ppm	Total C%	Orgnc C%	Crbnt C%	Ash %	pH	Quartz	Oligclas	Micrclin	LayerSil
				Special samples-continued						
HWC2003	169	11.23	11.23	0.01L	78.9	6.9	27.09	5.93	3.42	61.38
HWC2004	131	7.68	0.57	7.11	95.2	8.8	11.58	4.59	0.00	21.44
HWC2005	258	1.67	0.46	1.21	95.6	8.6	34.32	8.85	4.10	43.27
HWC2101	168	0.25	0.19	0.06	97.4	8.6	47.27	11.07	0.00	40.35
HWC2102	243	0.67	0.67	0.01L	95.5	8.2	30.27	11.94	0.00	55.00
HWC2103	216	14.13	14.06	0.07	72.0	5.0	21.90	1.71	0.00	63.51
HWC2104	378	6.81	1.23	5.58	97.8	9.3	20.75	10.72	0.00	13.79
HWC2105	264	2.31	0.97	1.34	94.8	8.8	30.68	9.01	2.85	47.12
HWC2301	297	6.92	6.92	0.01L	82.6	4.0	34.55	10.48	0.00	52.95
HWC2302	197	0.84	0.38	0.46	96.8	7.1	52.07	9.39	7.53	27.07
HWC2303	161	6.71	1.62	5.09	80.7	8.5	17.74	2.40	0.00	33.67
HWC2501	168	7.91	0.55	7.36	96.5	8.6	28.30	13.61	0.00	44.89
HWC2502	197	0.74	0.08	0.66	97.3	9.2	41.45	11.34	3.90	39.53
HWC2503	377	1.41	0.18	1.23	94.2	8.9	36.54	12.07	0.00	42.36
HWC2504	124	26.20	26.20	0.01L	53.8	5.3	17.95	0.00	0.00	60.86
HWC2505	180	7.47	1.56	5.91	78.4	8.4	16.36	0.00	0.00	22.94
HWC2506	283	1.64	1.13	0.51	94.2	8.1	27.67	2.96	6.73	55.66
HWC2507	283	2.85	1.21	1.64	96.0	8.1	34.54	2.76	6.17	39.51
HWC2508	266	13.06	13.06	0.01L	73.6	6.0	20.14	0.00	1.71	70.21
HWC2509	331	2.18	1.64	0.54	95.5	8.7	43.97	2.68	8.23	38.33
HWC2510	314	1.10	0.57	0.52	95.7	8.1	52.61	5.92	12.47	23.86
HWC2511	257	3.04	2.62	0.42	92.5	8.1	26.66	0.00	2.19	61.71
HWC2512	462	1.13	0.30	0.83	98.0	9.2	46.56	4.06	5.86	37.83
HWC2701	388	1.87	0.35	1.48	97.1	8.3	36.41	8.66	3.97	38.22
HWC2702	146	29.04	28.97	0.07	48.9	4.9	11.96	0.00	0.00	57.47
HWC2703	478	1.28	1.08	0.20	95.5	8.6	53.14	6.30	6.67	32.92
HWC2704	286	0.56	0.29	0.27	96.3	9.0	29.88	11.26	0.00	54.58
HWC2705	199	6.06	0.42	5.64	97.2	9.3	27.26	7.83	18.10	35.51
HWC2706	273	2.14	0.99	1.15	95.5	9.2	32.81	12.14	0.00	44.74
HWC2707	224	4.28	0.66	3.62	97.2	9.6	40.25	12.94	0.00	11.22
HWC2708	210	19.54	19.54	0.01L	65.5	5.0	19.85	2.12	4.41	55.17
HWC2709	244	1.25	0.57	0.68	96.1	8.3	46.72	6.86	10.71	30.37
HWC2710	496	1.57	0.56	1.01	96.1	9.2	46.38	3.04	13.09	30.13
HWC2711	260	1.72	0.57	1.15	95.6	9.3	44.93	3.51	9.22	34.74
HWC2712	306	2.09	1.65	0.44	95.7	8.9	40.33	1.54	5.77	45.23

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Sample	Calcite	Mg-Calc	Dolomite	Ca-Dolo	Siderite	Ca-Sider	Pyrite	Marcasit	Gypsum	Smectite
				Special samples-continued						
HWC2003	0.00	0.00	1.46	0.00	0.71	0.00	0.00	0.00	0.00	6.14
HWC2004	0.00	56.28	4.11	0.00	0.00	0.00	0.00	2.01	0.00	1.07
HWC2005	4.31	0.00	4.82	0.00	0.32	0.00	0.00	0.00	0.00	8.65
HWC2101	0.00	0.00	1.31	0.00	0.00	0.00	0.00	0.00	0.00	28.25
HWC2102	0.00	0.00	0.00	0.16	0.60	0.00	2.02	0.00	0.00	16.50
HWC2103	0.00	0.00	0.00	0.00	0.00	0.00	12.89	0.00	0.00	31.75
HWC2104	0.00	48.16	3.85	0.00	0.00	2.72	0.00	0.00	0.00	1.38
HWC2105	3.39	0.00	3.30	0.00	0.75	2.91	0.00	0.00	0.00	16.49
HWC2301	0.00	0.00	0.00	0.22	0.42	0.00	1.39	0.00	0.00	2.65
HWC2302	0.00	0.00	2.45	0.00	0.00	0.00	1.49	0.00	0.00	8.12
HWC2303	0.00	0.00	2.30	0.00	0.00	43.90	0.00	0.00	0.00	8.42
HWC2501	0.00	0.00	0.00	13.20	0.00	0.00	0.00	0.00	0.00	2.24
HWC2502	1.10	0.00	2.67	0.00	0.00	0.00	0.00	0.00	0.00	21.74
HWC2503	4.56	0.00	4.47	0.00	0.00	0.00	0.00	0.00	0.00	10.59
HWC2504	0.00	0.00	0.00	0.00	0.00	0.00	21.19	0.00	0.00	45.65
HWC2505	0.00	0.00	0.00	0.00	0.00	60.70	0.00	0.00	0.00	4.59
HWC2506	0.12	0.00	5.52	0.00	0.00	0.00	1.34	0.00	0.00	16.70
HWC2507	4.03	0.00	10.52	0.00	0.75	1.71	0.00	0.00	0.00	7.90
HWC2508	0.00	0.00	0.00	0.00	0.00	0.00	7.94	0.00	0.00	28.08
HWC2509	0.56	0.00	4.76	0.00	0.00	0.48	1.00	0.00	0.00	15.33
HWC2510	0.00	0.00	3.13	0.00	0.00	2.00	0.00	0.00	0.00	3.57
HWC2511	0.00	0.00	0.00	0.00	0.00	5.28	4.15	0.00	0.00	18.51
HWC2512	0.00	0.00	4.90	0.00	0.79	0.00	0.00	0.00	0.00	0.00
HWC2701	3.12	0.00	8.76	0.00	0.85	0.00	0.00	0.00	0.00	7.64
HWC2702	0.00	0.00	0.00	0.00	0.00	0.00	30.57	0.00	0.00	28.73
HWC2703	0.00	0.00	0.00	0.11	0.86	0.00	0.00	0.00	0.00	13.17
HWC2704	0.00	0.00	1.44	0.00	0.87	0.00	1.96	0.00	0.00	27.29
HWC2705	0.00	0.00	10.22	0.00	1.09	0.00	0.00	0.00	0.00	1.77
HWC2706	3.00	0.00	5.09	0.00	0.47	1.74	0.00	0.00	0.00	16.66
HWC2707	0.00	26.66	8.69	0.00	0.00	0.23	0.00	0.00	0.00	1.68
HWC2708	0.00	0.00	0.00	0.00	0.00	0.00	18.45	0.00	0.00	24.83
HWC2709	0.00	0.00	4.25	0.00	0.00	0.00	1.09	0.00	0.00	9.11
HWC2710	0.61	0.00	5.44	0.00	0.23	1.08	0.00	0.00	0.00	4.51
HWC2711	0.77	0.00	5.80	0.00	0.00	1.02	0.00	0.00	0.00	8.69
HWC2712	2.07	0.00	3.58	0.00	0.00	1.49	0.00	0.00	0.00	18.09

APPENDIX C

Complete tabulation of chemical and mineralogical data, Hanging Woman Creek overburden rock cores, dry weight basis-continued

Special samples-continued

Sample	Illite	Chlorite	Kaolinit
HWC2003	13.41	12.28	24.56
HWC2004	9.64	9.64	1.07
HWC2005	12.98	12.98	8.65
HWC2101	4.04	4.04	4.04
HWC2102	16.50	16.50	5.50
HWC2103	12.70	3.17	15.87
HWC2104	2.76	2.07	7.58
HWC2105	7.07	11.78	11.78
HWC2301	23.83	0.00	26.48
HWC2302	1.35	1.35	16.24
HWC2303	8.42	8.42	8.42
HWC2501	17.95	17.95	6.73
HWC2502	3.95	3.95	9.88
HWC2503	8.47	10.59	12.71
HWC2504	0.00	0.00	15.22
HWC2505	4.59	2.29	11.47
HWC2506	8.35	8.35	22.26
HWC2507	3.95	1.98	25.68
HWC2508	10.53	3.51	26.08
HWC2509	3.83	3.83	15.33
HWC2510	3.57	3.57	13.12
HWC2511	18.51	6.18	18.51
HWC2512	11.34	11.34	15.13
HWC2701	11.47	9.56	9.56
HWC2702	0.00	0.00	28.73
HWC2703	4.94	1.65	13.17
HWC2704	10.92	10.92	5.46
HWC2705	12.42	12.42	8.87
HWC2706	8.95	13.42	6.71
HWC2707	1.12	2.24	6.17
HWC2708	8.28	8.28	13.79
HWC2709	3.04	3.04	15.19
HWC2710	3.01	3.01	19.58
HWC2711	3.47	1.74	20.84
HWC2712	6.78	4.52	15.83

Appendix D

Description of soil series and map units.

[The following descriptions are copied from the unpublished manuscript of the Big Horn County soil survey report. It is reprinted here with permission of the Soil Conservation Service. The descriptions are subject to change pending final correlation and editing. English units of measure have been retained.]

Alice Series

The Alice series consists of deep, sloping and moderately steep and rolling, well-drained soils on narrow footslopes, fans, and valley bottoms. Slopes range from 4 to 15 percent. They formed in sandy alluvium from calcareous sandstone at elevations of 2900 to 3700 feet.

Vegetation is green sagewort, little bluestem, prairie sandreed, sideoats grama, blue grama, broom snakeweed, ragweed, and eriogonum. Precipitation is 13 to 14 inches; mean-annual-soil temperature is 47 to 49 degrees F.; and the frost-free period is 115 to 125 days.

Typically the surface layer is grayish brown fine sandy loam about 2 inches thick. The subsoil is grayish brown and light olive brown sandy loam about 10 inches thick. The substratum is light olive brown, light yellowish brown, and pale yellow sandy loam and loamy sand. The soil has moderately rapid permeability and an effective-rooting depth of 60 or more inches. The water-holding capacity is moderate. Most of these soils are used for range. Small areas are in dryland hay.

A typical profile of Alice sandy loam on grassland is, as follows:

A -- 0 to 2 inches, grayish brown (2.5Y 5/3) fine sandy loam, very dark grayish brown (2.5Y 3/2) moist; weak coarse crumb structure parting to single grain; soft, very friable, nonsticky and slightly plastic; many fine and very fine roots; clear smooth boundary.

B21 -- 2 to 6 inches, grayish brown (2.5Y 5/2) sandy loam, very dark grayish brown (2.5Y 3/2) moist; moderate, coarse prismatic structure; slightly sticky and slightly plastic; common fine roots; gradual wavy boundary.

B22 -- 6 to 12 inches, light olive brown (2.5Y 5/3) sandy loam, olive brown (2.5Y 4/3) moist; slightly hard, friable, nonsticky and slightly plastic; common fine roots; gradual wavy boundary.

C1 -- 12 to 17 inches, light olive brown (2.5Y 5/3) light sandy loam, olive brown (2.5Y 4/3) moist; massive, slightly

hard, friable, nonsticky and slightly plastic; very slightly effervescent; a few very fine roots; clear smooth boundary.

C2 -- 17 to 28 inches, light yellowish brown (2.5Y 6/3) light sandy loam, light olive brown (2.5Y 5/3) moist; massive; hard, friable, nonsticky and slightly plastic; slightly effervescent; a few fine, soft masses of lime; a few very fine roots; gradual wavy boundary.

C3 -- 28 to 41 inches, light yellowish brown (2.5Y 6/3) light sandy loam, light olive brown (2.5Y 5/3) moist; massive; slightly hard, friable, nonsticky and slightly plastic; slightly effervescent; a few very fine roots; gradual wavy boundary.

C4 -- 41 to 65 inches, pale yellow (2.5Y 7/3) heavy loamy sand, olive (2.5Y 5/3) moist; massive, slightly hard, very friable, nonsticky and slightly plastic; slightly effervescent.

The A-horizon ranges in color from dark grayish brown to light olive brown. The texture is sandy loam or fine sandy loam. The B2 horizon thickness ranges from 5 to 10 inches. Clay content ranges between 12 and 18 percent.

Alice soils are associated with Nelson, Travessilla, and Thedalund soils. They have greater depth to sandstone than the Nelson soils and have greater depth to sandstone than the Travessilla soils. They are more sandy than the Thedalund soils.

Alice fine sandy loam, 4 to 15 percent slopes (Ar).

This soil is on footslopes, fans, and valley bottoms in 20 to 30-acre-size areas. Slopes are smooth and mainly 4 to 10 percent. Steeper slopes occur below the higher hills and the residual soils that border the deep valleys. Slope length is 200 to 400 feet. Included with this soil in mapping are small areas of Olney fine sandy loam on gentle slopes of the larger fans. Also included is a 50 to 75-feet-wide band of Glenberg fine sandy loam on 8 to 15 percent slopes below the sandstone ledges and outcrops that border the valley. The soil profile is the one described as typical for the series. Runoff is slow, and the wind erosion hazard is severe. This soil is used for range and dry cropland.

(Capability Unit IIIe-3 Dryland; Sandy range site 10-14-inch precipitation zone; Windbreak Suitability Group 2M).

Arvada Series

The Arvada series consists of deep, nearly level and gently sloping, well-drained, alkali-affected soils, on fans, terraces, and valley bottoms. Slopes range from 0 to 4 percent. They formed in mixed clay and loam alluvium at elevations of 2800 to 3800 feet. The annual precipitation is 12 to 14 inches; mean-annual-soil temperature is 47 to 49 degrees F.; and the frost-free period is 115 to 125 days.

Typically the surface layer is grayish brown and light brownish gray silt loam about 3 inches thick. The subsoil is grayish brown clay and silty clay about 15 inches thick. The substratum is pale brown silty clay and grayish brown clay to 60 or more inches. Alkalinity ranges from moderate at the surface to strong in the lower subsoil and upper substratum. The soil is very slowly permeable and the effective-rooting depth is 60 inches or more. Available-water-holding capacity is moderate or high. These soils are used mostly for range. A few small areas are used for dry cropland where they are mixed with other soils.

A typical profile of Arvada silty clay loam on grassland is, as follows:

A21 -- 0 to 2 inches, grayish brown (10YR 5/2) silt loam, dark grayish brown (10YR 4/2) moist; weak, thin platy structure, soft, very friable, nonsticky, slightly plastic; common vesicular pores; abrupt smooth boundary.

A22 -- 2 to 3 inches, light brownish gray (10YR 6/2) silt loam, dark brown (10YR 4/3) moist; moderate, very thin platy structure; many clean sand grains coating top of the plates; soft, very friable, nonsticky and slightly plastic; common vesicular pores; abrupt smooth boundary.

B2t -- 3 to 13 inches, grayish brown (10YR 5/2) clay, very dark grayish brown (10YR 3/2) moist; strong medium, prismatic structure parting to strong medium blocks, extremely hard, very firm, very sticky and very plastic; patches of moderately thick clay films on ped surfaces; a few fine roots; clear wavy boundary.

B3cacs -- 13 to 18 inches, grayish brown (10YR 5/2) silty clay, dark grayish brown (10YR 4/2) moist; moderate, medium blocky structure; strongly effervescent, a few fine threads and crystals of lime and gypsum; gradual wavy boundary.

C1 -- 18 to 30 inches, grayish brown (10YR 5/2) silty clay, dark grayish brown (10YR 4/2) moist; massive; very hard, very firm, very sticky and very plastic; strongly effervescent; gradual wavy boundary.

C2 -- 30 to 60 inches, pale brown (10YR 6/3) silty clay, dark yellowish brown (10YR 3/4) moist; massive; very hard, firm, sticky and plastic; strongly effervescent.

Depth to the calcareous material ranges from 8 to 18 inches. The A2-horizon-color range is grayish brown to light gray. The B2t-horizon-texture range is clay to clay loam and silty clay. The C2 horizon may be stratified with textures of loam, silt loam, and sandy loam below the 30-inch depth.

Arvada soils are associated with Bone, Hydro, and Thurlow soils. They lack the flocculated, salt horizon of the Bone soils. They differ from the Thurlow soils in having an A2 horizon and higher alkalinity. They lack the transition A & B or B & A horizons of Hydro soils.

Arvada silty clay loam, 0 to 4 percent slopes (Ayd).

This soil is on fans and terraces in small stream valleys. The slopes are mainly 0 to 2 percent with steeper slopes along the shallow drainageways and at the edge of the terraces. The soil has the profile described as typical for the series. Included with this soil in mapping is Bone clay that lies in the barren, microdepressions on the land surface. The soil has slow runoff and a slight erosion hazard. The soil is used for range.

(Capability Unit VIs-1 Dryland; Clayey range site 10-14-inch precipitation zone; Windbreak Suitability Group 3S).

Arvada-Bone clays, 0 to 4 percent slope (Aye).

This complex comprises nearly level and gently sloping soils on small terraces and fans in wide valleys. It consists of 60 to 80 percent Arvada clay, 15 to 30 percent Bone clay, and 5 to 10 percent Hydro silty clay loam. The land surface has distinct microdepressions 3 to 8 inches deep occupied by the nearly barren Bone soils. Continuous areas of the individual soils are usually less than 1/2 acre. Slopes are 1 percent or less on the terraces and 3 to 4 percent on the fans and the terrace edges. The soils have profiles similar to the typical ones described for their respective series. The runoff is slow and erosion hazard is slight. These soils are used for range.

(Capability Unit VIs-1 Dryland; Pan Spot range site 10-14-inch precipitation zone; Windbreak Suitability Group 4).

Colby Series

The Colby series consists of deep, well-drained soils on terraces, ridge tops and hills several hundred feet above the present river floodplain. The terrain is nearly level to moderately steep and gently undulating to hilly. Slopes range from 1 to 35 percent. They formed in alluvium and aeolian silts at elevations of 2900 to 3600 feet.

The vegetation is mainly western wheatgrass, prairie junegrass, and green needlegrass. Precipitation is 13 to 15 inches; the mean-annual-soil temperature is 47 to 49 degrees F.; and the frost-free period is 110 to 125 days.

Typically the surface layer is grayish brown silt loam about 5 inches thick. The underlying layer is light brownish gray or pale yellow silty clay loam to 60 inches or more. The soil is moderately permeable and has an effective-rooting depth of 60 or more inches. Available-water-holding capacity is high. These soils are used for dry cropland, hayland, pasture, and range.

A typical profile of Colby silt loam on grassland is, as follows:

A11 -- 0 to 2 inches, grayish brown (2.5Y 5/2) silt loam dark grayish brown (2.5Y 4/2) moist; weak very fine platy structure; hard, friable, slightly sticky and slightly plastic; slightly effervescent, many fine roots; clear smooth boundary.

A12 -- 2 to 5 inches, grayish brown (2.5Y 5/2) silt loam, dark grayish brown (2.5Y 4/2) moist; weak, coarse prismatic structure; hard, friable, slightly sticky and slightly plastic; many fine roots; common fine pores; slightly effervescent; clear wavy boundary.

C1 -- 5 to 11 inches, light brownish gray (2.5Y 6/2) light silty clay loam, light olive brown (2.5Y 5/3) moist; weak prismatic structure parting to weak, medium and coarse blocks; hard, friable, sticky and plastic; many fine roots; common fine pores; strongly effervescent; a few fine soft masses of lime; gradual wavy boundary.

C2ca -- 11 to 15 inches, pale yellow (2.5Y 7/3) silty clay loam, light olive brown (2.5Y 5/4) moist; weak coarse prismatic structure parting to weak, coarse blocks; very hard, friable, very sticky and plastic; a few fine roots; a few medium and coarse soft masses of lime; common fine pores; strongly effervescent; gradual wavy boundary.

C3ca -- 15 to 27 inches, pale yellow (2.5Y 7/3) silty clay loam, light olive brown (2.5Y 5/3) moist; weak, coarse prismatic structure parting to weak coarse and medium

blocks; very hard, firm, sticky and very plastic; a few fine roots; a few fine pores; a few medium and coarse soft masses of lime; strongly effervescent; gradual wavy boundary.

C4ca -- 27 to 34 inches, light gray (2.5Y 7/2) heavy silt loam, light olive brown (2.5Y 5/3) moist; weak, coarse blocky structure; very hard, friable, sticky and plastic; a very few fine roots; common fine pores; a few coarse soft masses of lime; strongly effervescent; gradual wavy boundary.

C5 -- 34 to 65 inches, light yellowish brown (2.5Y 5/3) silt loam, light olive brown (2.5Y 5/3) moist; massive; hard, friable, sticky and plastic; strongly effervescent.

The depth to the segregated lime is 8 to 10 inches. The clay content in the 10 to 40-inch depth is 20 to 35 percent.

Colby soils are associated with Clapper, Beauvais, Keiser, and Midway soils. They contain less lime and coarse fragments than the Clapper soils. They have greater depth to shale bedrock than the Midway soils.

<u>Colby-Midway complex, 8 to 15 percent slopes (CW).</u>

This complex comprises moderately steep soils on thinly-mantled gravel terraces and benches where drainageways have cut through the mantle into underlying shale. In places, aeolian silts have thickened the original terrace deposits. It consists of 50 to 80 percent Colby silty clay loam, 20 to 35 percent Harvey loam. The soil pattern is a combination of Colby soils on the mantled ridges and upper sides of the main valley and its tributary drainageways, and Midway soils on the lower side of the ridges and valleys. Harvey soils are on the narrow ridges with slopes of 12 to 15 percent. The soils have profiles similar to the typical ones described for their respective series. Surface gravels cover 1 to 15 percent of all the soils. The runoff is rapid and the erosion hazard moderate. These soils are used for range, pasture, and hayland.

(Capability Unit IVe-3 Dryland; Clayey range site 10-14-inch precipitation zone; Windbreak Suitability Group 3M).

Cushman Series

The Cushman series consists of moderately deep, undulating, well-drained soils on smooth ridges and hilltops in the sedimentary plains. The slopes range from 4 to 8 percent. They formed in place from underlying, mixed shale and sandstone at elevations of 3100 to 3800 feet.

The vegetation is mainly needle-and-thread, big sage, western wheatgrass, and fringed sagewort. Annual precipitation is 12 to 14 inches; the mean-annual-soil temperature is 47 to 49 degrees F.; the frost-free period is 115 to 125 days.

Typically the surface layer is brown loam about 5 inches thick. The subsoil is brown and light brownish gray clay loam and loam about 11 inches thick. The substratum is light gray loam. Shale and sandstone bedrock are at about 30 inches. The soil reaction is mildly alkaline throughout. The soil is noncalcareous to about 9 inches and moderately calcareous below this depth. Lime in the substratum is segregated into soft masses and nodules. The soil has moderate permeability and an effective-rooting depth of about 36 inches. Available-water-holding capacity is low or moderate. These soils are used for range and for dry cropland.

A typical profile of Cushman loam cultivated is, as follows:

Ap -- 0 to 5 inches, brown (10YR 5/3) loam, dark brown (10YR 3/3) moist; cloddy; hard, friable, very sticky and plastic; a few fine roots; abrupt smooth boundary.

B2t -- 5 to 10 inches, brown (10YR 5/3) clay loam, dark brown (10YR 4/3) moist; moderate medium prismatic structure parting to moderate medium blocks; hard, firm, very sticky and plastic; thin patchy clay films on ped surfaces; a few very fine roots; clear wavy boundary.

B3 -- 10 to 16 inches, light brownish gray (2.5Y 6/2) loam, grayish brown (2.5Y 5/2) moist; moderate medium prismatic structure, parting to moderate medium blocks; thin patchy clay films on ped surfaces; strongly effervescent, a few medium lime mottles and some film lime; a few very fine roots; clear wavy boundary.

C1ca -- 16 to 25 inches, light gray (2.5Y 7/2) loam, light olive brown (2.5Y 5/3) moist; weak angular blocky structure; hard, friable, sticky and plastic; strongly effervescent, common medium and coarse lime mottles; a few very fine roots; gradual wavy boundary.

C2 -- 25 to 35 inches, light gray (2.5Y 7/2) loam, grayish brown (2.5Y 5/2) moist; massive; hard, friable, sticky and plastic; strongly effervescent, a few coarse lime

mottles; clear wavy boundary.

C3 -- 35 to 40 inches, soft platy shale.

Depth to the shale and sandstone is 20 to 40 inches. The depth to the calcareous part of the soil is 9 to 11 inches. Clay content of the B2t is 27 to 33 percent. Ap-horizon-color range is grayish brown to brown. The C horizon has a color range of light yellowish brown to light gray.

Cushman soils are associated with Thedalund, Midway, and Renohill soils. They have a B2t horizon not present in the Thedalund soils and Midway soils. They are less clayey than the Midway and Renohill soils.

Cushman loam, undulating, 4 to 8 percent slopes (Cz).

This undulating soil is on sedimentary plains. It occupies smooth ridges and hills on the broad divides between major stream valleys. The areas range from 10 to 50 acres in size. The soil has the profile described as typical for the series. Included with this soil in mapping are small areas of Heldt, Midway, and Thurlow soils. The runoff is medium and the erosion hazard is moderate. This soil is used for range, hayland, and dry cropland.

(Capability Unit IIIe-3 Dryland; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 3M).

Fort Collins Series

The Fort Collins series consists of deep, nearly level to sloping and rolling, well-drained soils on terraces and fans. Slopes range from 0 to 15 percent. They formed in loam and clay loam alluvium in stream valleys at elevations of 2850 to 3400 feet.

The vegetation is mainly blue grama, needle-and-thread, big sagebrush, and cheatgrass. The annual precipitation is 12 to 14 inches; the mean-annual-soil temperature is 47 to 49 degrees F.; and the frost-free period is 115 to 125 days.

Typically the surface layer is grayish brown loam about 4 inches thick. The subsoil is brown clay loam and loam about 7 inches thick. The substratum is light brownish gray loam to 60 or more inches. These soils have moderate permeability and an effective-rooting depth of 60 or more inches. Available-water-holding capacity is high. These soils are used for irrigated and dry cropland and for range.

A typical profile of Fort Collins loam on grassland is, as follows:

A -- 0 to 3 inches, grayish brown (10YR 5/2) loam, dark grayish brown (10YR 4/2) moist; moderate, medium platy structure; soft, friable, nonsticky and nonplastic; clear smooth boundary.

AB -- 3 to 4 inches, brown (10YR 5/3) loam, dark grayish brown (10YR 4/2) moist; moderate, medium platy structure; slightly hard, friable, slightly sticky and slightly plastic; clear smooth boundary.

B21t -- 4 to 9 inches, brown (10YR 5/3) clay loam, dark brown (10YR 4/3) moist; moderate, medium prismatic structure parting to moderate medium blocks; hard, firm, sticky and slightly plastic; thin continous clay films on ped surfaces; gradual wavy boundary.

B22t -- 9 to 12 inches, brown (10YR 5/3) clay loam brown (10YR 4/3) moist; moderate, medium prismatic structure parting to moderate, medium blocks; hard, firm, slightly sticky and slightly plastic; thin patchy clay films on ped surfaces; gradual wavy boundary.

B3ca -- 12 to 22 inches, grayish brown (10YR 5/2) loam, grayish brown (10YR 4/2) moist; weak, weak prismatic structure parting to weak medium blocks; hard, friable, slightly sticky and pastic; strongly effervescent; a few fine lime mottle. Clear wavy boundary.

C1 -- 22 to 27 inches, light brownish gray (2.5Y 6/2) loam, light olive brown (2.5Y 5/3) moist; weak, coarse prismatic structure; hard, friable, slightly sticky and slightly plastic; strongly effervescent; a few medium and coarse lime mottles; gradual wavy boundary.

C2 -- 27 to 33 inches, light brownish gray (2.5Y 6/2) loam, light olive brown (2.5Y 5/3) moist; massive; hard, friable, slightly sticky and slightly plastic; strongly effervescent; gradual wavy boundary.

C3 -- 33 to 65 inches, light gray (2.5Y 7/2) loam, grading to silt loam below 53 inches; massive; strongly effervescent.

The depth to the calcareous soil ranges from 7 to 12 inches. Coarse fragments in the upper 24 inches of the profile range from 0 to 10 percent. Soil-color hue is 10YR to 5Y. The A-horizon color range is light brownish gray and grayish brown. The B2t-horizon color range is grayish brown and olive. Stratification in the C horizon includes textures of fine sandy loam, clay loam, and silt loam.

Fort Collins soils are associated with Thurlow, McRae, and Hydro soils. They contain less clay than the Thurlow soils and more clay than the McRae soils. They lack the A2 and B & A horizons of the Hydro soils.

Fort Collins loam, 2 to 4 percent slopes (Fk).

This soil is on fans and terraces in river and intermittent stream valleys. The areas are 5 to 40 acres in size. The soil profile is the one described as typical for the series. In the areas of gravel terraces the soil may include strata of loamy sand below 30 inches. Included with the soil in mapping are small spots of McRae and Thurlow soils. The runoff is slow and the erosion hazard moderate. This soil is used for irrigated and dry cropland, hayland, and range.

(Capability Unit IIIe-3 Dryland, IIe-1 Irrigated; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 1).

Fort Collins loam, 4 to 8 percent slopes (Fm).

This soil is on footslopes, fans, and terraces. It lies in 20 to 50-acre patches in the tributary drainageways to major stream valleys. Slope length ranges between 250 and 450 feet. The soil has a profile similar to the typical one described for the series. Included with this soil in mapping on the footslopes are narrow bands of McRae soils immediately below the residual soils of the valley rim. The runoff is medium and the erosion

hazard moderate. This soil is used for dry and irrigated cropland, hayland, and range.

(Capability Unit IIIe-3 Dryland, IIIe-1 Irrigated; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 1).

Gilt Edge Series

The Gilt Edge series consists of deep, nearly level and gently sloping and gently undulating sodium-affected soils on terraces. Slopes range from 0 to 4 percent. They formed in alkaline alluvium at elevations of 2900 to 3600 feet.

The vegetation is mainly western wheatgrass, Sandberg bluegrass, big sage, needle-and-thread, fringed sagewort, and blue grama. The annual precipitation is 12 to 14 inches; the mean-annual-soil-temperature is 47 to 49 degrees F.; and the frost-free period is 115 to 125 days.

Typically the surface layer is light brownish gray and grayish brown loam and silt loam about 3 inches thick. The subsoil is grayish brown clay and silty clay about 13 inches thick. The substratum is pale yellow silty clay and silty clay loam to 40 or more inches. The soil is moderately alkaline in the surface and subsoil, and strongly alkaline in some part of the substratum. These soils have moderately slow to slow permeability and an effective-rooting depth of 40 or more inches. Available-water-holding capacity is 7 to 10 inches. These soils are used for dry cropland and range. They are suited for irrigation.

A typical profile of Gilt Edge silty clay loam on grassland is, as follows:

A21 -- 0 to 1 inch, light brownish gray (10YR 6/2) loam, dark brown (10YR 4/3) moist; vesicular massive structure; soft, very friable, nonsticky and slightly plastic; abrupt smooth boundary.

A22 -- 1 to 3 inches, grayish brown (10YR 5/2) silt loam, dark brown (10YR 5/2) silt loam, dark brown (10YR 3/3) moist; moderate, medium platy structure; slightly hard, friable, slightly sticky and plastic; clean sand grains coat the top of plates giving 6/2 dry color; moderately alkaline, pH 8.1; abrupt smooth boundary. (A2 horizon is 2 to 4 inches thick.)

B21t -- 3 to 6 inches, grayish brown (10YR 5/2 crushed, 5/3 coated) clay, dark grayish brown (10YR 4/2) moist; moderate fine flat-topped prismatic structure parting to strong fine blocks; very hard, firm, very sticky and very plastic; moderately thick patchy clay films on ped surfaces; a few fine pores; moderately alkaline, pH 8.2; clear smooth boundary.

B22t -- 6 to 10 inches, grayish brown (10YR 5/2 crushed, 5/3 coated) clay, dark grayish brown (10YR 4/2 crushed, 4/3 coated) moist; moderate, medium prismatic structure parting to strong medium blocks; very hard, firm, very

sticky and very plastic; thin patchy clay films coating the ped surfaces; a few fine root channels and pores; slightly effervescent; moderately alkaline, pH 8.2; clear smooth boundary. (B2t horizon is 6 to 11 inches thick.)

B3ca -- 10 to 16 inches, grayish brown (2.5Y 6/2) silty clay, light olive brown (2.5Y 5/3) moist; moderate, medium prismatic structure parting to moderate, medium prismatic structure parting to moderate, medium blocks; very hard, firm, very sticky and very plastic; strongly effervescent; common, medium masses of lime; moderately alkaline, pH 8.4; clear wavy boundary. (3 to 8 inches thick)

C1 -- 16 to 27 inches, pale yellow (2.5Y 7/3) silty clay, light yellowish brown (2.5Y 6/3) moist; weak, coarse prismatic structure parting to weak coarse blocks; very hard, firm, very sticky and very plastic; strongly effervescent; common fine threads and masses of lime; moderately alkaline, ph 8.2; gradual wavy boundary.

C2 -- 27 to 42 inches, pale yellow (2.5Y 7/4) silty clay loam, light yellowish brown (2.5Y 6/4) moist; massive very hard, friable, sticky and very plastic; strongly effervescent; moderately alkaline, pH 8.3; gradual wavy boundary.

C3 -- 42 to 60 inches, pale yellow (2.5Y 7/4) silty clay loam, light yellowish brown (2.5Y 6/4) moist; massive structure; very hard, friable, sticky and plastic; strongly effervescent; strongly alkaline, pH 8.7.

The surface texture includes silt loam and silty clay loam. The B2t horizon has 50 to 60 percent clay with structure of strong, flat-topped or rounded prisms. The structure peds have staining and coatings that are light reflective. B2t-horizon-color range is light olive brown, dark grayish brown, and brown. The C-horizon-color hues are 5Y through 10YR. Color ranges from pale brown to pale yellow. Segregated lime is in few to common fine threads and soft masses. Segregated gypsum crystals may occur at any depth below the B horizon. The C horizon has more than 15 percent exchangeable-sodium in some parts. A gravelly substratum may be present below 40 inches. A few pebbles may be present in all horizons.

Gilt Edge soils are associated with Bone, Hydro, Bew, and Shonkin soils. They lack the granulated salt horizon of the Bone soils. They have more clay in their B2t horizon than the Hydro soil. They are more alkaline than the Bew soils. They lack the thick A2 and B & A horizons of the Shonkin soils.

Gilt Edge silty clay loam, 2 to 4 percent slopes (Gd).

This gently sloping soil is on high gravel terraces and benches along the river valleys. The land surface includes low ridges, knolls, and crests of broad undulations separated by concave to level troughs. Slope length is 50 to 100 feet. Shallow drainageways near the terrace edge have 3 to 4 percent slopes. The soil profile is similar to the typical one described for the series. Included with this soil in mapping are small areas of Shonkin, Hesper, Keiser, and Hydro soils. Also included are small areas where gravel covers 15 to 20 percent of the soil surface. Along terrace edges and deep drainageways small areas of soil underlain by gravelly sand at depths as shallow as 30 inches are also included. The runoff is slow and the erosion hazard is slight. Areas of Shonkin soil are subject to flooding during spring snow melt. This soil is used for dry cropland and range. It is suitable for irrigation.

(Capability Unit IVs-2 Dryland, IVe-1 Irrigated; Dense clay range site 10-14-inch precipitation zone; Windbreak Suitability Group 2S.)

Appendix D

Haverson Series

The Haverson series consists of deep, nearly level and gently sloping, well-drained soils on floodplains, low terraces and terrace fronts in wide stream valleys. Slopes range from 0 to 35 percent. They formed in stratified alluvium of loam, silt loam, and fine sandy loam at elevations of 2800 to 3300 feet.

The vegetation is mainly Sandberg bluegrass, needle-and-thread, silver sage, curlycup gumweed, and cudweed sagewort. The annual precipitation is 12 to 14 inches; the mean-annual-soil temperature is 47 to 49 degrees F.; and the frost-free period is 115 to 125 days.

Typically the surface layer is grayish brown and light brownish gray stratified silt loam, loam, and fine sandy loam to 60 or more inches. These soils have moderate permeability and an effective-rooting depth of 60 or more inches. Available-water-holding capacity is moderate or high. These soils are used for irrigated and dry cropland and range.

A typical profile of Haverson loam cultivated is, as follows:

Ap1 -- 0 to 4 inches, grayish brown (2.5Y 5/2) heavy loam, dark grayish brown (2.5Y 4/2) moist; cloddy structure with surface of moderate coarse granules; hard, friable, slightly sticky and plastic; slightly effervescent; clear smooth boundary.

Ap2 -- 4 to 12 inches, grayish brown (2.5Y 5/2) heavy loam, dark grayish brown (2.5Y 4/2) moist; fragmental structure; hard, friable, slightly sticky and plastic; very few, very fine roots and pores; slightly effervescent; clear smooth boundary.

C1 -- 12 to 27 inches, light yellowish brown (2.5Y 6/3) loam, light olive brown (2.5Y 5/3) moist; massive; hard, friable, slightly sticky and slightly plastic; a few fine roots; common fine pores; strongly effervescent; gradual wavy boundary.

C2 -- 27 to 33 inches, light brownish gray (2.5Y 6/2) stratified silt loam sandy loam, light olive brown (2.5Y 5/3) moist; massive; slightly hard, friable, nonsticky and slightly plastic; a very few fine roots; strongly effervescent; gradual wavy boundary.

C3 -- 33 to 60 inches, light yellowish brown (2.5Y 6/3) light sandy loam, light olive brown (2.5Y 5/3) moist; massive; slightly hard, very friable, nonsticky hard, very friable, nonsticky and slightly plastic; slightly effervescent; a few faint, reddish brown mottles.

The texture of the A horizon is silty clay, silty clay loam, or loam. The soil-color hue is 10YR through 2.5Y. The A-horizon-color range is light brownish gray and light yellowish brown. The C-horizon-color range is light yellowish brown and light olive gray.

Haverson soils are associated with Lohmiller, Glenberg, and McRae soils. They contain less clay than the Lohmiller soils and have less sand than the Glenberg soils. They lack the B2 horizon and segregated lime of the McRae soils.

Haverson loam, 0 to 2 percent slopes (Hfa).

This nearly level soil is on river- and perennial-stream floodplains and low terraces. Most areas are nearly level and smooth, but, in places, old stream channel scars give local relief of 1 to 2 feet. It has the profile described as typical for the series. Included are some areas of soils that have gravelly sand at depths between 20 and 40 inches. These areas are marked by a special symbol on the soil maps. Surface runoff is slow, and the erosion hazard is slight. Spring flooding may occur in local areas for several days. Streambank erosion is a management problem along the perennial streams. This soil is suited to dry and irrigated cropland, hayland, and range.

(Capability Unit IIIc-1 Dryland; IIc-1 Irrigated; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 1.)

Haverson and Lohmiller soils, channeled, 0 to 35 percent slopes (HGb).

This undifferentiated soil group comprises nearly level to steep soils of stream valleys. This group consists of Haverson loam and silty clay loam, and Lohmiller silty clay loam. The amounts and kinds of these soils in any map area varies widely and no useful purpose would be served to separate them. Channel erosion and the extreme meander pattern divide the soils into 1/4 to 3-acre patches.

Locally runoff from tributary valleys floods some of the soils. Slopes are 0 to 4 percent on the valley bottom and 15 to 35 percent on the short terrace breaks and the sides of the stream channel. The soil profiles of the Haverson and Lohmiller soils in this association have the characteristics similar to those described for their respective series. Included in the mapping are spots of Hysham silty clay loam and Haverson soils, saline. The runoff is slow and the erosion hazard is severe. This soil association is suited to range.

(Capability Unit VIe-1 Dryland; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 4.)

Appendix D

Heldt Series

The Heldt series consists of deep, nearly level to moderately steep, well-drained soils on fans, terraces, and footslopes. Slopes range from 0 to 15 percent. They formed in silty clay loam alluvium in the wide river and intermittent stream valleys, at elevations of 2800 to 3500 feet.

The vegetation is mainly western wheatgrass, green needlegrass, big sage, and blue grama. The annual precipitation is 12 to 14 inches; the mean-annual-soil temperature is 47 to 49 degrees F.; and the frost-free period is 115 to 125 days.

Typically the surface layer is grayish brown silty clay loam about 6 inches thick. The substratum is light yellowish brown and light gray silty clay loam and clay loam to 60 or more inches. These soils have slow permeability and an effective-rooting depth of 60 or more inches. These soils are used for dry and irrigated cropland and range. Available-water-holding capacity is high.

A typical profile of Heldt silty clay loam on grassland is, as follows:

A -- 0 to 4 inches, grayish brown (2.5Y 5/2) light silty clay loam, dark grayish brown (2.5Y 4/2) moist; weak, fine platy structure parting to weak fine granules; hard, friable, slightly sticky and plastic; slightly effervescent; clear smooth boundary.

B2 -- 4 to 10 inches, grayish brown (2.5Y 5/2) silty clay loam, dark grayish brown (2.5Y 4/2) moist; weak, medium prismatic structure parting to moderate, medium blocks; hard, friable, sticky and plastic; slightly effervescent; clear wavy boundary.

C1 -- 10 to 15 inches, light yellowish brown (2.5Y 6/3) silty clay loam, light olive brown (2.5Y 5/3) moist; weak, medium prismatic structure parting to weak, coarse and medium blocks; hard, friable, sticky and plastic; strongly effervescent; a few lime threads; clear wavy boundary.

C2 -- 15 to 23 inches, light yellowish brown (2.5Y 6/3) silty clay loam, light olive brown (2.5Y 5/3) moist; weak, medium blocky structure; hard, friable, sticky and plastic; strongly effervescent, common thread lime; gradual wavy boundary.

C3 -- 23 to 44 inches, light gray (2.5Y 7/2) silty clay loam, grayish brown (2.5Y 5/2) moist; massive; hard, friable, sticky and plastic; strongly effervescent; gradual boundary.

C4 -- 44 to 60 inches, light brownish gray (2.5Y 6/2) clay loam, grayish brown (2.5Y 5/2) moist; massive; hard, friable, sticky and plastic; strongly effervescent.

The 10 to 40 inch section is a heavy silty clay loam or silty clay with clay content ranging from 38 to 50 percent. Coarse fragments of shale and gravel range from 0 to 10 percent. Soil-color hue is 2.5Y through 5Y. The A-horizon-color range is light brownish gray and olive gray. The Cca-horizon- color range is light gray and pale olive.

Heldt soils are associated with Thurlow, Kyle, and McRae soils. They lack the B2t horizon of the Thurlow soils. They contain less clay than the Kyle soils and have more clay than the McRae soils.

Heldt silty clay loam, 4 to 8 percent slopes (Hlc).

This soil is on footslopes and fans in river valleys and below shale, rock-capped escarpments in intermittent stream valleys. In the valleys that drain gravel-capped land there are scattered surface gravels. Slopes are generally smooth but some areas have deep gullies spaced at 500 to 800 feet. The soil has the profile described as typical for the series. Included with this soil in mapping are isolated, 1 to 2-acre knobs of Midway silty clay loam. Below steep shale escarpments there is an inclusion of a band of Lohmiller silty clay loam. Surface runoff is rapid and the erosion hazard is moderate. This soil is suited to most irrigated and dryland crops, hayland, and range. Erosion control is the main management problem.

(Capability Unit IIIe-3 Dryland; IIIe-1 Irrigated; Clayey range site 10-14-inch precipitation zone; Windbreak Suitability Group 1.)

Heldt silty clay loam, 8 to 15 percent slopes (Hld).

This soil is on long, narrow areas on footslopes in intermittent stream valleys. Slopes are mainly 10 to 15 percent with length ranging between 150 and 400 feet. The soil profile is similar to the typical one described for the series. Included with this soil in mapping is a band of Lohmiller silty clay loam below the shale outcrops on the valley rim. The surface runoff is rapid, and the erosion hazard is severe. Most areas of this soil receive runoff from steeper soils that lie above them. This soil is suited to dryland crops and to range. Erosion control is an important management problem on this soil.

(Capability Unit IVe-3 Dryland; Clayey range site 10-14-inch precipitation zone; Windbreak Suitability Group 1.)

Heldt-Hysham silty clay loams, 2 to 4 percent slopes (Hlg).

This soil complex comprises gently sloping soils on fans, low terraces, and bottoms in intermittent stream valleys. Slopes are mainly 2 percent on the valley bottom and 3 or 4 percent on the fans and valley sides. The complex consists of about 75 percent Heldt silty clay loam and about 25 percent Hysham silty clay loam. The Hysham soil is in spots about 15 feet wide where vegetation is thin and the surface is light gray. Runoff is medium and erosion hazard is moderate. The Heldt and Hysham soils in this complex have characteristics similar to those described for their respective series. This complex is suited to range and dry cropland. Crop growth on the Hysham soil is affected by the alkalinity of the soil and by poor structure and tilth when plowed.

(Capability Unit IIIe-3 Dryland; Clayey range site 10-14-inch precipitation zone; Windbreak Suitability Group 3S.)

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Hydro Series

The Hydro series consists of deep, nearly level to sloping, well-drained soils on terraces, fans, and benches in and along the large stream valleys. Slopes range from 0 to 8 percent. They formed in alluvium of clay loam and silty clay loam containing a moderate amount of sodium at elevations of 3000 to 3800 feet.

The vegetation is mainly western wheatgrass, blue grama, Sandberg bluegrass, big sage, and plains reedgrass. The annual precipitation is 13 to 15 inches; the mean-annual-soil temperature is 47 to 49 degrees F.; and the frost-free period is 110 to 120 days.

Typically the surface layer is light brownish gray, very fine sandy loam about 2 inches thick; The subsurface layer is brown loam about 3 inches thick. The subsoil is grayish brown silty clay and silty clay loam about 22 inches thick. The substratum is light brownish gray and olive gray silty clay loam, silty clay, and silt loam to 60 or more inches. The soil reaction is moderately alkaline in the subsoil and strongly alkaline in the upper substratum. These soils have slow permeability and an effective-rooting depth of 60 or more inches. Available-water-holding capacity is moderate or high. These soils are used for dry cropland and range. They are suitable for irrigation.

A typical profile of Hydro loam on grassland is, as follows:

A2 -- 0 to 2 inches, light brownish gray (10YR 6/2) very fine sandy loam, very dark grayish brown (10YR 3/2) moist; moderate, thin platy structure; slightly hard, very friable, nonsticky and slightly plastic; abundant clean sand grains; clear smooth boundary.

A2&B2 -- 2 to 5 inches, brown (10YR 5/3) loam, dark brown (10YR 3/3) moist; weak, medium prismatic structure parting to moderate thin plates; slightly hard, friable, slightly sticky and slightly plastic; clean sand grains coating the tops of the structure plates; clear smooth boundary.

B2&A2 -- 5 to 7 inches, brown (10YR 5/3) silty clay loam, dark brown (10YR 3/3) moist; moderate, medium prismatic structure parting to moderate, medium plates; hard, friable, sticky and plastic; coating of clean sand grains on the tops of the plates; thin, patchy clay films on ped faces; clear wavy boundary.

B21t -- 7 to 12 inches, grayish brown (10YR 5/2) silty clay, dark grayish brown (10YR 4/2) moist; moderate, medium prismatic structure parting to strong, fine and medium blocks; very hard, firm, very sticky and very plastic;

moderately thick, patchy clay films on ped surfaces; clear wavy boundary.

B22t -- 12 to 15 inches, grayish brown (2.5Y 5/2) silty clay, olive brown (2.5Y 4/3) moist; moderate, medium prismatic structure parting to strong, fine blocks; very sticky and very plastic; moderately thick, patchy clay films on ped surfaces; clear wavy boundary.

B23t -- 15 to 21 inches, grayish brown (2.5Y 5/2) silty clay, olive brown (2.5Y 4/3) moist; moderate, medium prismatic structure parting to strong fine blocks; very hard, firm, very sticky and very plastic; moderately thick, patchy clay films on ped surfaces; slightly effervescent; clear wavy boundary.

B3ca -- 21 to 27 inches, light brownish gray (2.5Y 6/2) silty clay, light olive brown (2.5Y 5/3) moist; moderate, medium prismatic structure parting to moderate fine blocks; very hard, firm, very sticky and very plastic; strongly effervescent; a few fine lime mottles; gradual wavy boundary.

C1ca -- 27 to 32 inches, light brownish gray (2.5Y 6/2) silty clay, grayish brown (2.5Y 5/2) moist; weak, medium blocky structure; very hard, firm, very sticky and very plastic; strongly effervescent; a few, medium lime mottles; gradual wavy boundary.

C2 -- 32 to 39 inches, olive gray (5Y 5/2) silty clay loam, olive (5Y 4/3) moist; massive; very hard, firm, sticky and plastic; strongly effervescent; gradual boundary.

IIC -- 39 to 65 inches, light olive gray (5Y 6/2) stratified silt loam and very fine sandy loam, olive gray (5Y 4/2) moist; soft, friable, slightly sticky and slightly plastic; strongly effervescent.

Soil-color hues are 7.5YR through 5Y. The noncalcareous part of the solum is 12 to 18 inches thick. The A2-horizon-texture range is loam to silt loam. It's color range is grayish brown to light gray. The B2t-horizon-clay content ranges from 45 to 55 percent. The B2t-horizon-color range is dark brown to brown. The Cca horizon has a color range of light olive brown and light olive gray.

Hydro soils are associated with Allentine, Bone, Thurlow, Gilt Edge, and Shonkin soils. They have a thicker A2 horizon and greater solum thickness than the Allentine soils. They lack the granular salt horizon of the Bone soils. They differ from the Thurlow soils in having A2 and B & A horizons. They lack the abrupt boundary of the A2 and B2 horizons and have less clayey B2t horizons than the Gilt Edge soils. They have thinner A2

horizons and lack the mottling of the Shonkin soils.

Hydro loam, 0 to 8 percent slopes (Hna).

This nearly level to sloping soil is in 5 to 35-acre areas on fans, footslopes, and terraces in intermittent stream valleys. Slope length ranges between 300 and 600 feet. Slope gradient is 0 to 2 percent on the terraces, 2 to 5 percent on the fans and 5 to 8 percent on the footslopes. It has the soil profile described as typical for the series. Included in mapping were small areas of Allentine silty clay in microdepressions mainly on 1 percent slopes of the terraces. Surface runoff is slow to medium, and the erosion is slight to moderate. This soil is suited to dryland crops, hayland, and range. Erosion control is a necessary part of soil management on steep slopes.

(Capability Unit IIIc-1 Dryland; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 2S.)

Hydro silt loam, 2 to 4 percent slopes (Hnc).

This gently sloping soil occurs on fans and loess-mantled hills along major stream valleys. Its profile differs from the typical one described for the series by having grayish brown color and silt loam texture in the surface layers. Included in mapping on the mantled hills were some areas of Richfield silty clay loam on convex, 4 percent slopes. Surface runoff is medium and the erosion hazard is moderate. This soil is suited to dryland crops and to range. It is well suited for irrigated crops.

(Capability Unit IIIe-2 Dryland; IIIs-1 Irrigated; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 2S.)

Hydro-Allentine complex, 4 to 8 percent slopes (Hnh).

This complex comprises sloping soils of stream valleys. About 75 percent is Hydro loam and about 25 percent is Allentine clay loam. The Allentine clay loam has a thin, grass cover and it occupies 2 to 4-inch deep microdepressions surrounded by the Hydro loam. In cultivated fields the Allentine soil has hard surface clods. The Hydro and Allentine soils in this complex have profiles similar to those described for their respective series. Runoff is medium and the erosion hazard is moderate. This complex is suited to dryland crops and to range. Most areas when cultivated need protection against runoff from soils that lie above them. Maintaining good tilth is important on the Allentine soil.

(Capability Unit IVs-2 Dryland; Pan Spots range site 10-14-inch precipitation zone; Windbreak Suitability Group 3S.)

Hysham Series

The Hysham series consists of deep, nearly level to moderately steep, well-drained, sodium-affected soils on terraces, fans, and footslopes in the river and intermittent stream valleys. Slopes range from 0 to 15 percent. They formed in alluvium of mixed loam, silt loam, and silty clay loam at elevations of 2850 to 3600 feet.

The vegetation is mainly plains prickly pear, greaseweed, silver sage, western wheatgrass, and Sandberg bluegrass. The annual precipitation is 13 to 14 inches; the mean-anual-soil temperature is 47 to 50 degrees F.; and the frost-free season is 115 to 125 days.

Typically the surface layer is light brownish gray silty loam about 1 inch thick. The underlying material is grayish brown or light olive brown silty clay loam to 60 or more inches. The soil reaction is strongly alkaline throughout. These soils have slow permeability and an effective-rooting depth of 60 or more inches. These soils are used for range and irrigated cropland.

A typical profile of Hysham silty clay loam on grassland is, as follows:

A -- 0 to 1 inch, light brownish gray (2.5Y 5/2) heavy silt loam, very dark grayish brown (2.5Y 3/2) moist; moderate thin platy structure; slightly hard, friable, slightly sticky and plastic; slightly effervescent; strongly alkaline, pH 9.0; clear boundary.

C1 -- 1 to 7 inches, grayish brown (2.5Y 5/2) silty clay loam, dark grayish brown (2.5Y 4/2) moist; moderate subangular blocky structure; hard, firm, sticky and plastic; strongly alkaline, pH 9.0; strongly effervescent; gradual boundary.

C2 -- 7 to 11 inches, grayish brown (2.5Y 5/2) heavy silty clay loam, dark grayish brown (2.5Y 4/2) moist; moderate medium subangular blocky structure; very hard, firm, sticky and very plastic; strongly alkaline, pH 8.9; strongly effervescent; gradual wavy boundary.

C3 -- 11 to 14 inches, grayish brown (2.5Y 5/2) silty clay loam; dark grayish brown (2.5Y 4/2) moist; weak fine subangular blocky structure; hard, friable, slightly sticky and plastic; strongly effervescent; strongly alkaline, pH 8.5; few fine salt threads and crystals; gradual wavy boundary.

C4 -- 14 to 23 inches, grayish brown (2.5Y 5/2) heavy silty clay loam, dark grayish brown (2.5Y 4/2) moist; weak fine subangular blocky structure; very hard, firm, sticky and plastic; strongly effervescent; strongly alkaline, pH 8.8;

common fine salt crystals; gradual wavy boundary.

C5 -- 23 to 43 inches, grayish brown (2.5Y 5/2) heavy silty clay loam, dark grayish brown (2.5Y 4/2) moist; weak fine subangular blocky structure parting to weak medium plates; very hard, firm sticky and plastic; strongly effervescent; strongly alkaline, pH 8.7; common fine salt crystals; gradual boundary.

C6 -- 43 to 63 inches, light olive brown (2.5Y 5/2) silty clay loam, olive brown (2.5Y 4/3) moist; massive structure; hard, friable, sticky and plastic; strongly effervescent; strongly alkaline, pH 8.6; few fine salt crystals.

Soil color hue is 2.5Y through 5Y. Texture of the 10 to 40-inch section is loam, clay loam, or silty clay loam with 20 to 35 percent clay. The Ap-horizon-color range is grayish brown to olive gray. The C-horizon-color range is light yellowish brown and pale olive. The gypsum and other salt crystals occur in few to common threads and clusters. Strata of fine sandy loam and loamy sand may occur at depths below 24 inches.

Hysham soils are associated with Lohmiller, Haverson, Glenberg, and Midway soils. They are more alkaline than these soils and have a crusted surface. They are not as sandy as the Glenberg soils and they lack the shale bedrock of the Midway soils.

Hysham loam, 0 to 2 percent slopes (Ho).

This soil is on terraces and fans in river valleys. It has a profile similar to the typical one described for the series. Included in the mapping were spots of Haverson loam making up as much as 25 percent of any map area. A water table below 3 feet is present in some spots during part of the growing season. Surface runoff is slow, and the erosion hazard is slight. This soil is suited to range. It is suited to alkali-tolerant, irrigated crops only after reclamation by drainage and leaching.

(Capability Unit VIs Dryland; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 3S.)

Lohmiller Series

The Lohmiller series consists of deep, nearly level to steep and undulating, well-drained soils on floodplains of rivers and streams and on fans and footslopes in intermittent stream valleys. Slopes range from 0 to 35 percent. They formed in calcareous, silty clay alluvium at elevations of 2800 to 3600 feet.

The vegetation is mainly western wheatgrass, blue grama, silver sage, and Sandberg bluegrass. Annual precipitation is 12 to 14 inches; the mean-annual-soil temperature is 47 to 49 degrees F.; and the frost-free period is 115 to 125 days.

Typically the surface layer is light brownish gray silty clay loam about 12 inches thick. The underlying material is light yellowish brown and pale olive stratified silty clay loam and silty clay to 60 or more inches. The permeability is moderately slow and the effective-rooting depth is 60 or more inches. The available-water-holding capacity is high. These soils are used for irrigated and dry cropland and for range.

A typical profile of Lohmiller silty clay loam, cultivated and irrigated is, as follows:

Ap1 -- 0 to 6 inches, light brownish gray (2.5Y 6/2) silty clay loam, dark grayish brown (2.5Y 4/2) moist; cloddy with a surface mulch of moderate fine to coarse granules; hard, firm, sticky and plastic; a few very fine roots and pores; strongly effervescent; clear smooth boundary.

Ap2 -- 6 to 12 inches, light brownish gray (2.5Y 4/2) heavy silty clay loam, dark grayish brown (2.5Y 4/2) moist; moderate, sharply angled blocky and fragmental structure; hard, firm, very sticky and very plastic; a few very fine roots and pores; strongly effervescent; clear wavy boundary.

C1 -- 12 to 17 inches, light brownish gray (2.5Y 6/2) light silty clay loam, light olive brown (2.5Y 5/3) moist; massive; hard, friable, sticky and plastic; a few very fine roots and pores; strongly effervescent; gradual wavy boundary.

C2 -- 17 to 33 inches, pale olive (5Y 6/3) heavy silty clay loam containing several 1 to 2-inch bands of heavy silty clay loam, olive (5Y 5/3) moist; massive; hard, friable, very sticky and very plastic; a very few fine roots; common fine pores; strongly effervescent; clear wavy boundary.

C3 -- 33 to 60 inches, light yellowish brown (2.5Y 6/3) light silty clay containing several thin bands of silty clay loam, light olive brown (2.5Y 5/3) moist; massive; very hard, firm, very sticky and very plastic; a few fine

pores; strongly effervescent.

Texture of the 10 to 40-inch section averages heavy silty clay loam with a clay content of 35 to 45 percent. Coarse fragments make up 0 to 10 percent of the material below 30 inches. Soil-color hue is 2.5Y and 5Y. The Ap horizon, which is 8 to 12 inches thick, is brownish gray or olive gray.

The Lohmiller soils are associated with Haverson and Kyle soils. They contain more clay than the Haverson and less clay than the Kyle soils.

Lohmiller silty clay loam, 4 to 8 percent slopes (Lr).

This sloping soil is on fans, footslopes, and terraces in intermittent stream valleys and at the junction of tributary drainageways with river valleys. The large fans and terraces are often dissected by an uncrossable, dry, stream channel. Most of the areas on the footslopes receive runoff from soils that lie above them. The soil profile is similar to the typical one described for the series. Surface runoff is rapid and the erosion hazard is moderate. This soil is suited to irrigated and dryland crops. It is also suited to range. Erosion control is an important management problem on the cultivated soil.

(Capability Unit IIIe-3 Dryland; IIIe-1 Irrigated; Clayey range site 10-14-inch precipitation zone; Windbreak Suitability Group 1.)

McRae Series

The McRae series consists of deep, nearly level to steep, well-drained soils on fans, footslopes, and eroded terraces and terrace fronts in river and intermittent stream valleys. Slopes range from 0 to 35 percent. They formed in loam and clay-loam alluvium at elevations of 2800 to 3800 feet.

Vegetation is mainly blue grama, needle-and-thread, western wheatgrass, big sage, and cheatgrass. Precipitation is 12 to 14 inches; mean-annual-soil temperature is 47 to 49 degrees F.; and the frost-free period is 115 to 125 days.

Typically the surface layer is grayish brown loam about 2 inches thick. The substratum is pale olive and pale yellow loam to 60 or more inches. The permeability is moderate and the effective-rooting depth is 60 inches or more. Available-water-holding capacity is high. These soils are used for irrigated and dry cropland and for range.

A typical profile of McRae loam on grassland is, as follows:

A -- 0 to 2 inches, grayish brown (2.5Y 5/2) loam, dark grayish brown (2.5Y 4/2) loam, dark grayish brown (2.5Y 4/2) moist; moderate, coarse platy structure; slightly hard, friable, nonsticky and slightly plastic; many fine and a few coarse roots; clear smooth boundary.

B21 -- 2 to 5 inches, grayish brown (2.5Y 5/2) heavy loam, olive brown (2.5Y 4/3) moist; moderate, coarse and medium prismatic structure parting to moderate coarse blocks; hard, friable, sticky and plastic; a few fine roots and pores; clear wavy boundary.

B22 -- 5 to 10 inches, light yellowish brown (2.5Y 6/3) heavy loam, light olive brown (2.5Y 5/3) moist; moderate coarse prismatic structure parting to moderate coarse blocks; hard, friable, slightly sticky and slightly plastic; stongly effervescent; a few fine, soft masses of lime; gradual wavy boundary.

C1ca -- 10 to 17 inches, pale olive (5Y 6/3) heavy loam, olive (5Y 5/3) moist; weak, coarse prismatic structure; hard, friable, sticky and plastic; strongly effervescent; a few fine and medium soft masses of lime; many fine and a few medium pores; gradual wavy boundary.

C2ca -- 17 to 24 inches, pale yellow (5Y 7/3) heavy loam, pale olive (5Y 6/3) moist; hard, friable, sticky and plastic; massive; hard, friable, sticky and plastic; strongly effervescent; a few fine and medium soft masses of lime; a few fine roots; many fine and a few medium pores; diffuse boundary.

C3 -- 24 to 63 inches, pale yellow (5Y 7/3) loam, pale olive (5Y 6/3) moist; massive; slightly hard, friable, slightly sticky and plastic; strongly effervescent; a few fine soft masses of lime; a few fine roots; common fine pores.

The texture of the surface layer is loam or silty clay loam. Coarse fragments in the soil range from 0 to 15 percent. Soil-color hue is 10YR through 5Y. The A1-horizon-color range is grayish brown and light brownish gray. The B2-horizon-color range is grayish brown, light yellowish brown, light brownish gray and pale brown. The Cca-horizon-color range is pale yellow, light yellowish brown and pale olive.

McRae soils are associated with Fort Collins, Thurlow, and Thedalund soils. They lack the B2t horizon of the Fort Collins and Thurlow soils. They lack the shale bedrock of the Thedalund soils.

McRae loam, 1 to 4 percent slopes (Mr).

This soil is in 10 to 25-acre areas on fans and footslopes in the river and intermittent stream valleys. The soil profile is similar to the typical one described for the series. Included in the mapping were areas with silt loam surface. Surface runoff is medium and the erosion hazard is moderate. This soil is suited to irrigated and dryland crops, hayland, and range.

(Capability Unit IIIe-3 Dryland; IIe-1 Irrigated; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 1.)

McRae loam, 4 to 8 percent slopes (Ms).

This soil is on footslopes and fans in intermittent and perennial stream valleys. The areas range in size from 15 to 50 acres and in places they are dissected by short gullies. Slope gradient increases from 4 percent at the valley bottom to 10 or 12 percent immediately below the residual soils that border the valleys. The soil profile is the typical one described for the series. A few surface gravels are present where gravel terraces border the valleys. Included in the mapping were areas with a silt loam surface. Surface runoff is medium, and the erosion hazard is moderate. Most areas receive runoff moisture from soils that lie above them. This soil is suited to irrigated and dryland crops, hayland, and range. Moisture conservation and erosion control are important problems in managing this soil.

(Capability Unit IIIe-3 Dryland; IIIe-1 Irrigated; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 1.)

Midway Series

The Midway series consists of shallow, sloping to steep and undulating to hilly, well-drained soils on sedimentary plains. Slopes range from 2 to 35 percent. They formed in place in materials weathered from silty clay loam and silty clay shales at elevations of 3000 to 4000 feet.

The vegetation is sideoats grama, green needlegrass, big sage, skunkbush sumac, western wheatgrass, and broom snakeweed. Annual precipitation is 12 to 14 inches; the mean-annual-soil temperature is 47 to 49 degrees F.; and the frost-free period is 105 to 115 days.

Typically the surface layer is light olive gray silty clay loam underlain by shale at about 11 inches. Shale chips make up 30 percent of the volume in the lower substratum. Permeability is slow and the effective-rooting depth is about 15 inches. Available-water-holding capacity is very low. These soils are used for range. Small areas are used for dry cropland.

A typical soil profile of Midway silty clay loam on grassland is, as follows:

A -- 0 to 2 inches, light olive gray (5Y 6/2) light silty clay loam, olive gray (5Y 5/2) strong, very fine granular structure; hard, friable, sticky and plastic; common, fine roots; slightly effervescent; clear smooth boundary.

C1 -- 2 to 5 inches, olive gray (5Y 5/2) silty clay loam olive gray (5Y 4/2) moist; moderate, thin platy structure; hard, firm, very sticky and plastic; many fine and microroots; many micropores; strongly effervescent; gradual wavy boundary.

C2 -- 5 to 11 inches, olive gray (5Y 5/2) silty clay loam, olive gray (5Y 4/2) moist; weak, coarse blocky structure; hard, firm, very sticky and very plastic; 30 percent of volume is fine, partly-weathered, shale chips; common fine roots; common, fine and micropores; strongly effervescent; diffuse wavy boundary.

C3 -- 11 to 14 inches, platy shale containing root mats between horizontal fractures.

Depth to the shale beds ranges from 6 to 20 inches. Clay content throughout the soil ranges from 35 to 45 percent. The soil-color hue is 2.5Y or 5Y. Texture of the A1 horizon is silty clay loam, clay loam, or clay. The color range is light olive brown, light olive gray, and light brownish gray. Volume of shale chips in the C horizon ranges from 5 to 35 percent.

Midway soils are associated with Thedalund, Lismas, Renohill, and Thurlow soils. They contain more clay than the

Thedalund soils and less clay than the Lismas soils. They have less depth to shale than the Renohill soils, and they lack the B2t horizon of the deep Thurlow soils.

Midway silty clay loam, undulating, 2 to 8 percent slopes (Mu).

This soil is in narrow, irregular areas on smooth ridges between intermittent stream valleys. Slopes range in length between 100 and 250 feet. Slopes are mainly 5 to 8 percent but range downward to 2 percent. The soil profile is similar to the typical one described for the series. Included with this soil in mapping were areas of Renohill silty clay loam in the heads of drainageways and spots having concave, 2 to 4 percent slopes. A few spots with a gravelly silty clay loam surface are also included. Surface runoff is medium and the erosion hazard is moderate. This soil is suited to dry cropland, pastures, and range. Moisture conservation is an important practice in managing the cultivated soil.

(Capability Unit IVe-3 Dryland; Clayey range site 10-14-inch precipitation zone; Windbreak Suitability Group 3M.)

Midway silty clay loam, rolling, 8 to 15 percent slopes (MVa).

This soil is on the drainage divides between major valleys. The areas consist of ridges and hills that separate the short tributary drainageways to the main valley. Where total relief is under 150 feet the soil extends from the valley floor to the top of the drainage divide. Where relief is greater than 150 feet, this soil lies above steeper Midway soils. The soil profile is similar to the typical one described for the series. Included with this soil in mapping were small areas of Heldt, Lohmiller, and McRae soils. These soils are in drainageways and on the narrow footslopes of the main valleys. Also included on the ridge crests were areas of Thedalund loam and Nelson sandy loam. The surface runoff is rapid and the erosion hazard is severe. This soil is suited for range.

(Capability Unit VIe-1 Dryland; Clayey range site 10-14-inch precipitation zone; Windbreak Suitability Group 3M.)

Midway-Thedalund complex, rolling, 8 to 15 percent slopes (MVe).

This complex comprises rolling soils of the sedimentary plains. About 55 percent is Midway silty clay loam, about 30 percent is Thedalund loam, and about 15 percent is Thurlow and Heldt silty clay loams. The Midway and Thedalund soils occupy no predictable place on the landscape but the Thurlow and Heldt soils are on the footslopes in the wide valleys and drainageways. The Midway and Thedalund soils in this complex have profiles similar to those for their respective series. Surface runoff is

rapid and the erosion hazard is severe. This complex is suited to range.

(Capability Unit VIe-1 Dryland; Clayey range site 10-14-inch precipitation zone; Windbreak Suitability Group 3M.)

Midway-Thedalund complex, hilly, 8 to 35 percent slopes (MVf).

This complex comprises hilly soils of the sedimentary plains. Slopes are mainly 15 to 35 percent but range downward to 8 percent. Midway silty clay loam makes up about 60 percent of the complex, Thedalund loam is about 25 percent, and shale and rock outcrop are about 15 percent. The soils occupy no predictable place on the land. The shale outcrop is mostly on the south and west faces of the ridges and hills or along the rims of the deep valleys. The shale outcrops may include sandstone ledges 5 to 30 feet thick. Slopes are 8 to 10 percent on the ridge tops, 15 to 35 percent on the valley sides, and 35 percent or more on the shale outcrops. North and east slopes may have 10 to 40 percent canopy of ponderosa pine and juniper. The Midway and Thedalund soils in this complex have profiles similar to those described for their respective series. Mapped with these soils on the ridges were areas of Cushman loam and Renohill silty clay loam. Narrow footslopes of Thurlow silty clay loam were included in the wide valleys. Runoff is rapid and the erosion hazard is severe. Runoff from the shale areas carries large amounts of sediment. This complex is used for range and game range.

(Capability Unit VIe-1 Dryland; Thin Hill range site 10-14-inch precipitation zone; Windbreak Suitability Group 4.)

Shale outcrop-Midway complex, 25 to 90 percent slopes (SOc).

This complex is on deeply dissected, clay-shale highlands with 50 to 200 feet of relief. Areas occur as single, nearly perpendicular escarpments along a valley or a number of closely spaced, narrow ridges and drainageways at the head of valley. Single, escarpment areas include one or two 5 to 7-foot thick sandstone ledges mixed with shale. The complex consists of 35 to 70 percent shale outcrop and 25 to 65 percent Midway silty clay loam. The Midway silty clay loam is on ridgetops at heads of drainageways and on the lower one-third of the escarpment. The Midway soil has a profile similar to the typical one described for the series. Surface runoff is rapid. The erosion hazard is severe. Erosion is active. Runoff water carries a large amount of sediment. This complex is suited to range.

(Capability Unit VIIe Dryland; Shale range site 10-14-precipitation zone; Windbreak Suitability Group 4.)

Nelson Series

The Nelson series consists of moderately deep, undulating and rolling, well-drained soils on hills and ridges of sedimentary plains. Slopes are mainly 4 to 15 percent but range downward to 2 percent and upward to 20 percent. They are formed from calcareous, weakly consolidated sandstones at elevations of 3000 to 3800 feet.

The vegetation is mainly prairie sandreed, dryland sedges, silver sage, green sagewort, yucca, and bluebunch wheatgrass. Annual precipitation is 13 to 14 inches; mean-annual-soil temperature is 48 to 50 degrees F.; and the frost-free period is 115 to 125 days.

Typically the surface layer is light olive brown and grayish brown fine sandy loam about 5 inches thick. The underlying material is light olive brown, light yellowish brown grading to pale yellow sandy loam resting on sandstone at about 29 inches. Permeability is moderately rapid and the effective-rooting depth is about 30 inches. Available-water-holding capacity is low. These soils are used for range.

A typical profile of Nelson fine sandy loam on grassland is, as follows:

A -- 0 to 3 inches, light olive brown (2.5Y 5/3) fine sandy loam, dark grayish brown (2.5Y 4/2) moist; single grain structure breaking from a weak crust; soft, very friable, nonsticky and slightly plastic; clear smooth boundary.

AC -- 3 to 5 inches, grayish brown (2.5Y 5/2) fine sandy loam, dark grayish brown (2.5Y 4/2) moist; weak coarse prismatic structure; soft, very friable,

C1 -- 5 to 16 inches, light olive brown (2.5Y 5/3) sandy loam, dark grayish brown (2.5Y 4/2) moist; weak coarse prismatic structure; slightly hard, very friable, nonsticky and slightly plastic; slightly effervescent; diffuse boundary.

C2 -- 16 to 21 inches, light yellowish brown (2.5Y 6/3) sandy loam, light olive brown (2.5Y 5/3) moist; massive; slightly hard; friable, nonsticky and slightly plastic; strongly effervescent; diffuse boundary.

C3 -- 21 to 29 inches, pale yellow (5Y 7/3) sandy loam, pale olive (5Y 6/3) moist; massive with some evidence of plates of the rock structure; slightly hard, friable, nonsticky and slightly plastic; strongly effervescent; clear wavy boundary.

C4 -- 29 to 44 inches, pale yellow (5Y 7/3) sandstone, (5Y 6/3) moist; banded soft sandstone; strongly effervescent.

Depth to the calcareous soil ranges from 0 to 6 inches. Depth to sandstone and loam shale ranges from 20 to 40 inches. Content of coarse fragments ranges from 0 to 15 percent. Color hue is 2.5Y or 10YR in the surface and upper part of the underlying material. The lower part of the underlying material has hue of 2.5Y or 5Y.

Nelson soils are associated with Alice, Tullock, and Thedalund soils. They have lighter-colored surfaces and bedrock at shallower depths than the Alice soils. They have more clay than the Tullock soils and are more sandy than the Thedalund soils.

Nelson-Alice fine sandy loams, rolling, 8 to 20 percent slopes (Ne).

This complex comprises rolling soils on sedimentary plains. Slopes are mainly 8 to 15 percent but range upward to 20 percent. The complex consists of 40 to 60 percent Nelson fine sandy loam, 30 to 45 percent Alice fine sandy loam, and 10 percent Travessilla sandy loam and rock outcrop. The Nelson soils are on crests and upper sides of ridges and knolls. The Alice soils are on the narrow sides and in the heads of the drainageways and on footslopes below the Nelson soils. The Travessilla soils are around the rock outcrops. The Nelson and Alice soils in this complex have profiles similar to those described for their respective series. Surface runoff is medium and the erosion hazard is severe. This complex is suited to range.

(Capability Unit IVe-3 Dryland; Sandy range site 10-14-inch precipitation zone; Windbreak Suitability Group 3M.)

Thedalund Series

The Thedalund series consists of moderately deep, undulating to very steep, well-drained soils on sedimentary plains. Slopes range from 4 to 90 percent. They formed in materials weathered in place from shale at elevations of 2800 to 3800 feet.

Vegetation is mainly western wheatgrass, needle-and-thread, sideoats grama, dryland sedges, and big sagebrush. Annual precipitation is 12 to 14 inches; mean-annual-soil temperature is 48 to 50 degrees F.; and the frost-free period is 105 to 125 days.

Typically the surface layer is grayish brown loam about 2 inches thick. The underlying material is olive brown, light yellowish brown, and light gray loam resting on loam shale at about 28 inches. A few shale and sandstone fragments occur below 20 inches. Permeability is moderate and the effective-rooting depth is about 28 inches. The available-water-holding capacity is low or moderate. These soils are used for range. Small areas included with deeper soils are in dry cropland.

A typical profile of Thedalund loam on grassland is, as follows:

A -- 0 to 2 inches, grayish brown (2.5Y 5/2) loam, dark grayish brown (2.5Y 4/2) moist; weak, coarse crumb structure; slightly hard, very friable, slightly sticky and slightly plastic; slightly effervescent; common very fine roots; clear smooth boundary.

C1 -- 2 to 8 inches, light olive brown (2.5Y 5/3) heavy loam, olive brown (2.5Y 4/3) moist; weak, coarse prismatic structure; hard, friable, slightly sticky and slightly plastic; slightly effervescent; a few fine threads and soft masses of lime; many very fine pores; common very fine roots; gradual wavy boundary.

C2 -- 8 to 14 inches, light yellowish brown (2.5Y 6/3) heavy loam, olive brown (2.5Y 4/3) moist; weak, coarse prismatic structure; hard, friable, slightly sticky and plastic; strongly effervescent; a few fine soft masses of lime; common very fine pores and roots; gradual wavy boundary.

C3 -- 14 to 22 inches, light yellowish brown (2.5Y 6/3) loam, light olive brown (2.5Y 5/3) moist; massive; slightly hard, friable, slightly sticky and plastic; strongly effervescent; common, fine, soft masses of lime; a few very fine roots; common very fine pores; gradual wavy boundary.

C4 -- 22 to 28 inches, light gray (5Y 7/2) loam, olive (5Y 5/3) moist; very weak, coarse platy structure; slightly hard, friable, sticky and plastic; a few shale and sandstone

chips; strongly effervescent; common, medium soft masses of lime; a few very fine roots; common very fine pores; diffuse boundary.

C5 -- 28 to 37 inches, platy loam shale, hard when dry; a few very fine roots.

The 10- to 40-inch section is loam or light clay loam with the clay content ranging from 18 to 30 percent. Content of coarse fragments range from 0 to 20 percent. The A and upper C horizons have hues of 2.5Y and 10YR. The lower C horizon has hue of 2.5Y and 5Y. Color range in the A horizon is grayish brown, brown, and dark grayish brown. The lower C horizon has a color range of light olive brown, light yellowish brown, and pale olive.

Thedalund soils are associated with Midway, Cushman, and McRae soils. They contain less clay and have greater depth to shale than the Midway soils. They lack the B2t horizon of the Cushman soils and have less depth to bedrock than the McRae soils.

Thedalund-McRae loams, dissected, 4 to 35 percent slopes (THd).

This complex comprises undulating to steep soils of the sedimentary plains. Thedalund loam makes up 40 to 65 percent of the complex; McRae loam is about 30 to 50 percent; and Kim loam is 5 to 15 percent. The Thedalund loam is in 2 to 10-acre patches on the shale knolls and ridges where slopes are 8 to 25 percent. The McRae loam is on the fans and footslopes surrounding or lying between the Thedalund soils. Narrow gullies and coulees that are 5 to 15 feet deep have Kim loam on the sides and edges. Slopes are 20 to 35 percent. The Thedalund and McRae soils in this complex have profiles similar to those described for their respective series. Surface runoff is rapid and the erosion hazard is severe. Most areas receive runoff from the highlands that border them. This complex is suited to range.

(Capability Unit IVe-3 Dryland; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 2M.)

Thedalund-Midway complex, rolling, 8 to 15 percent slopes (THe).

This complex comprises rolling soils of the sedimentary plains. Thedalund loam makes up 40 to 70 percent of the complex; Midway silty clay loam is 20 to 40 percent; and McRae loam is 10 to 20 percent. The Thedalund and Midway soils lie in no predictable pattern on the hills and ridges. The McRae loam lies in the shallow heads of drainageways. The Thedalund and Midway soils in this complex have profiles similar to those described for their respective series. The surface runoff is medium and the erosion hazard is moderate. This complex is suited to range.

(Capability Unit IVe-3 Dryland; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 3M.)

Thedalund-Rock outcrop complex, hilly, 15 to 35 percent slopes (THg).

This complex comprises hilly soils of the sedimentary plains. The complex consists of 40 to 70 percent Thedalund loam, 10 to 30 percent Thedalund loam, 10 to 30 percent Midway silty clay loam, and 10 to 20 percent rock and loam, 10 to 30 percent Midway silty clay loam, 10 to 20 percent rock and shale outcrop, and 5 to 15 percent McRae loam. The Thedalund loam and Midway silty clay loam occur in no predictable pattern on the land but the Midway soil is usually around the shale outcrops on the hills and valley sides having 25 to 35 percent slopes. The McRae soil is in 1 to 5-acre patches in the wide valleys. The Thedalund and Midway soils in this complex have profiles similar to those described for their respective series. The surface runoff is rapid and the erosion hazard is severe. Runoff water carries a moderate amount of sediment. This complex is suited to range and game range.

The timbered areas in this complex are mainly in deep, narrow valleys and north-facing hillsides. The principal tree species are ponderosa pine and Rocky Mountain juniper. The average site index for the ponderosa pine is about 65. The stands are generally open with only isolated areas being overstocked. Timber harvest is limited to scattered areas that are overstocked. Most areas are accessible for logging and fire control.

(Capability Unit VIe-1 Dryland; Thin Hilly range site 10-14-inch precipitation zone; Windbreak Suitability Group 4.)

Thedalund-Travessilla loams, rolling, 2 to 15 percent slopes (THk).

This complex comprises rolling soils of the sedimentary plains. Slopes are mainly 8 to 15 percent but range downward to 2 percent. The complex consists of about 40 percent Thedalund loam, about 25 percent Cushman loam, about 20 percent Travessilla channery loam, and about 15 percent Hydro loam. The Thedalund loam and Travessilla channery loam are on narrow ridges, on the crests of surface undulations and along the valley rim. Some bare rock outcrop and surface channers mark the Travessilla soils. The Cushman loam, which is on slopes of 4 to 5 percent, is on the side slopes of the ridges and the surface undulations and in the drainageways. The Hydro loam, which is on 2 percent slopes, is in the swales and troughs of the surface undulations where runoff water collects. The Thedalund, Cushman, and Travessilla soils in this complex have profiles similar to those described for their respective series. Included with these soils in mapping were 1/2 to 2-acre patches of Midway silty clay loam and Nelson sandy loam. Surface runoff is medium and the erosion

hazard is moderate. This complex is suited to range.
(Capability Unit VIs Dryland; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 3M.)

<u>Thedalund-Wibaux loams, undulating, 4 to 8 percent slopes (TH1).</u>

This complex comprises undulating soils of the sedimentary plains. About 45 percent is Thedalund loam, about 40 percent is Wibaux channery loam, and about 15 percent is Travessilla loam, Spearman loam, and Hydro loam. The Thedalund and Wibaux soils lie in a random pattern on all slopes in patches of less than 40 acres. The red color and the surface channers or porcelanite boulders mark the Wibaux soils. The Hydro soils are in the troughs between low ridges where surface water collects. The soils have profiles similar to those described as typical for their respective series. The surface runoff is medium and the erosion hazard is moderate. This complex is suited to range.
(Capability Unit VIs-1 Dryland; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 3M.)

<u>Thedalund-Wibaux complex, rolling, 8 to 15 percent slopes (THm).</u>

This complex comprises rolling soils of the sedimentary plains. The complex consists of 55 to 70 percent Thedalund loam, 20 to 35 percent Wibaux channery loam, and 5 to 15 percent McRae loam. The main soils have no fixed position on the land but the Wibaux soil is above any red-shale outcrops on the hillsides. In the wide valleys there is a band of Wibaux soils at the base of the bordering highlands. The McRae loam is in the main drainageways. The Thedalund and Wibaux soils in this complex have profiles similar to those described as typical for their respective series. Surface runoff is medium and the erosion hazard is moderate. This complex is suited to range.
(Capability Unit VIe-1 Dryland; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 3M.)

Thurlow Series

The Turlow series consists of deep, nearly level to moderately steep and rolling, well-drained soils on fans, terraces, and footslopes in river and intermittent stream valleys. Slopes range from 0 to 15 percent. They formed in calcareous alluvium from mixed shale and sandstone at elevations of 2800 to 3600 feet.

Vegetation is mainly western wheatgrass, blue grama, green needlegrass, and big sage. Annual precipitation is 12 to 14 inches; mean-annual-soil temperature is 48 to 50 degrees F.; and the frost-free period is 110 to 125 days.

Typically the surface layer is dark grayish brown silt loam about 2 inches thick. The subsoil is grayish brown, light olive brown, and pale olive heavy silty clay loam and silty clay about 18 inches thick. The substratum is light olive gray silty clay loam to 60 or more inches. Permeability is moderately slow and the effective-rooting depth is 60 or more inches. Available-water-holding capacity is high. These soils are used for irrigated and dry cropland and for range.

A typical profile of Thurlow silty clay loam on grassland is, as follows:

A -- 0 to 2 inches, dark grayish brown (2.5Y 4/2) silt loam, very dark grayish brown (2.5Y 3/2) moist; weak, very thin platy structure; soft, friable, slightly sticky and slightly plastic; many micro and fine roots; clear smooth boundary.

B1 -- 2 to 4 inches, grayish brown (2.5Y 5/2) silty clay loam, dark grayish brown (2.5Y 4/2) moist; weak, medium prismatic structure; hard, firm, sticky and plastic; common micro and very fine roots; common fine pores; clear smooth boundary.

B21t -- 4 to 9 inches, light olive brown (2.5Y 4/2) silty clay, dark grayish brown (2.5Y 4/2) moist; strong, medium prismatic structure parting to moderate, medium blocks; very hard, firm, very sticky and very plastic; common fine and microroots and pores; patches of moderately thick clay films on ped surfaces; clear smooth boundary.

B22t -- 9 to 13 inches, light olive brown (2.5Y 5/3) heavy silty clay loam, olive brown 2.5Y 4.3) moist; strong medium prismatic structure parting to moderate, medium blocks; very hard, firm, very sticky and very plastic; common very fine roots; many micro and fine pores; patches of thin clay films on ped surfaces; clear wavy boundary.

B3 -- 13 to 20 inches, pale olive (5Y 6/3) heavy silty clay loam, olive (5Y 5/3) moist; moderate, coarse and medium blocks; very hard, firm, very sticky and very plastic; common very fine roots; many very fine and micropores; slightly effervescent; gradual wavy boundary.

C1ca -- 20 to 26 inches, light olive gray (5Y 6/2) silty clay loam, olive (5Y 5/3) moist; moderate, coarse blocky structure; very hard, firm, sticky and plastic; a few very fine roots; many very fine and micropores; strongly effervescent; common, distinct soft masses of lime; gradual wavy boundary.

C2 -- 26 to 38 inches, light olive gray (5Y 6/2) silty clay loam, olive (5Y 5/3) moist; weak, medium blocky structure; very hard, friable, sticky and plastic; a few very fine roots and common, fine pores; strongly effervescent; a few fine threads and soft masses of lime; gradual wavy boundary.

C3 -- 38 to 49 inches, light olive gray (5Y 6/2) light silty clay loam, olive (5Y 5/3) moist; massive; hard, friable, sticky and plastic; strongly effervescent; a few medium and fine, soft masses of lime; diffuse wavy boundary.

C4 -- 49 to 61 inches, light olive gray (5Y 6/2) heavy silt loam, olive (5Y 5/3) moist; massive, hard, slightly sticky and plastic; strongly effervescent.

The noncalcareous part of the solum is 10 to 16 inches thick. Hue is 10YR through 5Y. The A1 horizon is silt loam or loam. The Ap horizon is silty clay loam or clay loam. Color range is grayish brown and light brownish gray. The B2t horizon contains 35 to 45 percent clay. Color range is grayish brown, light yellowish brown and brown. The Cca horizon has color range of light gray, pale yellow, light olive gray, and pale olive.

Thurlow soils are associated with Midway, Hydro, McRae, and Fort Collins soils. They contain more clay than the Fort Collins soils. They have a B2t horizon not present in the McRae soils. They lack the shale bedrock of the Midway soils. They differ from the Hydro soils in having an A & B or B & A horizons.

Thurlow silty clay loam, 1 to 4 percent slopes (Tm).

This soil is on fans and terraces in river and intermittent stream valleys. Slopes are mainly 1 to 2 percent on the terraces and 3 to 4 percent on the fans in intermittent stream valleys. The soil has a profile similar to the typical one described for the series. Surface runoff is slow and the erosion hazard is slight. This soil is suited to irrigated and dryland crops, hayland, and range.

(Capability Unit IIIe-3 Dryland; IIe-1 Irrigated; Clayey range site 10-14-inch precipitation zone; Windbreak Suitability Group 1.)

Thurlow silty clay loam, 4 to 8 percent slopes (Tn).

This soil is on footslopes and fans and at the heads of tributary drainageways of intermittent stream valleys. Slope length ranges from 200 to 600 feet. Shallow drainageways are included in the footslopes. The soil profile is the typical one described for the series. Included with this soil in mapping were areas of Heldt silty clay loam on the upper sides of the footslopes. Some map areas have 15 to 20 percent Midway silty clay loam. These occur as 2 to 4-acre knolls rising 10 to 15 feet above the surrounding Thurlow soil. Slopes range to 15 percent but are generally smooth enough to cross with tillage implements. The surface runoff is medium and the erosion hazard is moderate. This soil is suitable for irrigated and dryland corps, hay and range.

(Capability Unit IIIe-3 Dryland; IIIe-1 Irrigated; Clayey range site 10-14-inch precipitation zone; Windbreak Suitability Group 1.)

Thurlow-Midway silty clay loams, 4 to 15 percent slopes (To).

This complex comprises sloping and moderately steep soils in wide, intermittent stream valleys and below shale escarpment at the heads of major valleys. It occupies the fans, footslopes, and low knolls and short ridges that lie on the valley sides and bottom. The areas usually include the entire valley below the steeply rising hills and ridges that border the valley. Thurlow silty clay loam makes up 40 to 60 percent of the complex; Midway silty clay loam is 30 to 50 percent; and Lohmiller silty clay loam is 10 to 20 percent. The Thurlow silty clay loam is on the footslopes and fans in areas of less than 10 acres. Narrow drainageways dissect the areas of Thurlow soils. The Midway silty clay loam is on the knolls and short ridges scattered through the Thurlow soils or along the base of the highlands that border the valley. Slopes are 12 to 15 percent on the Midway soil. The Lohmiller silty clay loam is below shale outcrops on the valley rim or in a narrow band along the dry-stream channel. The Thurlow and Midway soils in this complex have profiles similar to those described for their respective series. Some map areas have inclusions of Thedalund loam and sandstone outcrops with the Midway soils. The surface runoff is medium and the erosion hazard is moderate. The Thurlow soils receive runoff from the soils on the valley sides. This complex is suited to range.

(Capability Unit IVe-3 Dryland; Clayey range site 10-14-inch precipitation zone; Windbreak Suitability Group 1.)

Travessilla Series

The Travessilla series consists of shallow, undulating and rolling, well-drained soils on sandstone plains. Slopes are mainly 4 to 15 percent but range downward to 2 percent. They formed in materials weathered in place from calcareous, hard sandstone at elevations of 3200 to 3800 feet.

Vegetation is mainly prairie sandreed, Indian ricegrass, skunkbush sumac, and blue grama. Annual precipitation is 12 to 14 inches; mean-annual-soil temperature is 50 to 55 degrees F.; and the frost-free period is 115 to 120 days.

Typically the surface layer is grayish brown sandy loam about 2 inches thick. The underlying material is channery sandy loam resting on hard sandstone at about 18 inches. Permeability is rapid and the effective-rooting depth is about 18 inches. Available-water-holding capacity is 1 to 3 inches. These soils are used for range.

A typical profile of Travessilla sandy loam on grassland is, as follows:

A -- 0 to 2 inches, grayish brown (10YR 5/2) sandy loam, dark grayish brown (10YR 4/2) moist; weak fine crumb structure parting to single grain, loose, friable, nonsticky and nonplastic; clear smooth boundary.

C1 -- 2 to 13 inches, pale brown (10YR 6/3) sandy loam brown (10YR 5/3) moist; weak coarse platy structure, soft friable, nonsticky and slightly plastic; strongly effervescent; gradual wavy boundary.

C2 -- 13 to 18 inches, pale brown (10YR 6/3) channery sandy loam, brown (10YR 5/3) moist; a mixture of partially weathered, horizontally oriented, 1/4-inch-thick-sandstone fragments separated by sandy loam residuum. Fragments make up about 35 percent of volume. Loose, nonsticky and nonplastic; strongly calcareous; abrupt wavy boundary.

R -- 18 to 20 inches, hard, calcareous sandstone.

The surface-layer-texture range is loam, channery loam and sandy loam. Depth to bedrock ranges from 6 to 20 inches. Coarse fragments of channer- and gravel-size range from 10 to 35 percent. Modally, there is no accumulated calcium carbonate in the soil but the upper bedrock may have thin lime casts on the underside of fragments. Hue is 2.5Y through 7.5YR. Color range in the control section brown, light brown, pale brown, and light yellowish brown. Clay range is 5 to 15 percent.

Travessilla soils are associated with Nelson, Thedalund, and Tullock soils. They have bedrock at shallower depths than these soils and contain more sand than the Thedalund soils.

Travessilla-Thedalund loam, rolling, 8 to 15 percent slopes (TS).

This complex comprises rolling soils of the sedimentary plains. About 40 percent is Travessilla loam and sandy loam; about 40 percent is Thedalund loam; and about 15 percent is rock outcrop. The soils occur in no predictable pattern on the land but the Thedalund loam is usually on the low ridges and hills where slopes are 8 to 15 percent. The Travessilla soils occur between the ridges where erosion has exposed the sandstone and sandy shales on slopes of 2 to 10 percent. Rock outcrop occurs level with the soil surface or as ledges on the lower sides of the ridges. The Travessilla and Thedalund soils in this complex have profiles with characteristics similar to those described for their respective series. Surface runoff is medium and the erosion hazard is moderate. This complex is suited to range.

(Capability Unit VIe Dryland; Silty range site 10-14-inch precipitation zone; Windbreak Suitability Group 3M.)

Vananda Series

The Vananda series consists of deep, nearly level to sloping and undulating, well-drained, sodium-affected soils on terraces, fans, and footslopes in river and stream valleys. Slopes range from 0 to 8 percent. They formed in alkaline, clay alluvium from fresh and salt-water shales at elevations of 2700 to 3800 feet.

Vegetation is mainly greasewood, Sandberg bluegrass, wild onion, and western wheatgrass. Annual precipitation is 13 to 14 inches; mean-annual-soil temperature is 48 to 50 degrees F.; and the frost-free period is 115 to 125 days.

Typically the surface layer is light brownish gray silty clay about 1 inch thick. The underlying material is grayish brown grading to olive gray clay to 60 or more inches. The soil is strongly alkaline in all parts. Permeability is very slow and the effective-rooting depth is 60 or more inches. Available-water-holding capacity is moderate or high. These soils are used for range and irrigated cropland.

A typical profile of Vananda clay on grassland is, as follows:

A -- 0 to 1 inch, light brownish gray (2.5Y 6/2) silty clay, olive gray (5Y 4/2) moist; strong fine granular structure in the crust; hard, firm, sticky and plastic; slightly effervescent; crust breaks with moderate pressure; abrupt boundary.

C1 -- 1 to 3 inches, grayish brown (2.5Y 5/2) clay, olive (5Y 4/3) moist; moderate coarse blocky structure; very hard, firm, very sticky and very plastic; strongly effervescent; clear boundary.

C2 -- 3 to 12 inches, grayish brown (2.5Y 5/2) clay, olive gray (5Y 4/2) moist; moderate medium coarse blocky structure; extremely hard, very firm, very sticky and very plastic; strongly effervescent; clear wavy boundary.

C3ca -- 12 to 16 inches, light olive gray (5Y 5/2) clay, olive gray (5Y 4/2) moist; fragmental structure; extremely hard, very firm, very sticky and very plastic; strongly effervescent; common gypsum and other salt crystals; gradual wavy boundary.

C4cs -- 16 to 29 inches, olive gray (5Y 5/1) clay, dark olive gray (5Y 3/2) moist; massive; extremely hard, very firm, very sticky and very plastic; strongly effervescent; common gypsum and other salt crystals; gradual wavy boundary.

C5 -- 29 to 60 inches, olive gray (5Y 5/1) clay, dark olive gray (5Y 3/2) moist; massive structure; extremely hard, very firm, very sticky and very plastic; strongly effervescent; few gypsum and salt crystals.

The 10 to 40-inch section has 45 to 60 percent clay. Color hue is 2.5Y or 5Y. Color range of the C horizons is light olive gray, olive gray, light gray, and pale olive. Quantities of gypsum crystals range from many to very few. The exchangeable-sodium percentage is greater than 7 and increases to more than 15 at about 20 inches. The soil profile ranges from slightly to strongly calcareous with a few fine segregations of lime below 10 inches.

Vananda soils are associated with Kyle, Arvada, Pierre, and Allentine soils. They are more alkaline than the Kyle and Allentine soils and they lack the shale bedrock of the Pierre soils. They lack the columnar B2t and the A2 horizons of the Arvada soils.

Vananda clay, 1 to 8 percent slopes (Vc).

This soil is in 20 to 100-acre patches in valleys of shale highlands. It occupies the terraces and fans of the wide valleys and the footslopes in the narrow valleys. The terraces include 4 to 5-foot deep, dry channels. The footslopes have narrow rills and gullies spaced 100 to 200 feet apart. The soil profile is the typical one described for the series. Included with this soil in mapping were small areas of Allentine and Kyle soils. The surface runoff is medium and the erosion hazard is moderate. This soil is suited for range.

(Capability Unit VIe-1 Dryland; Dense Clay range site 10-14-inch precipitation zone; Windbreak Suitability Group 3S.)

Appendix E.--Taxonomic properties of the Great Groups of soils

The properties given are in addition to those that define the higher taxonomic levels. Descriptions adapted from Soil Survey Staff, 1975]

Camborthids

Soils have one or more of the following characteristics:

-a cambic horizon (reddish or brownish)
-no argillic or natric horizon
-no salic horizon within 75 cm depth
-no calcic, petrocalcic, gypsic, or petrogypsic horizon or duripan within 1 m depth
-developed from post-Pleistocene sediments of low lime
-may be calcareous in all horizons

Haplargids

Soils have one or more of the following characteristics:

-an argillic horizon
-may have calcic horizon below the argillic
-no natric horizon
-no duripan or petrocalcic horizon within 1 m depth
-developed mostly on erosion surfaces or sediments of late-Pleistocene age with little or no lime

Haplustolls

Soils have one or more of the following characteristics:

-no argillic or natric horizon
-no duripan, or calcic or gypsic horizon within 1 m depth
-transition layer below mollic epipedon that is less than 25 percent by volume of filled animal burrows
-no petrocalcic horizon within 1.5 m depth
-a cambic horizon, <u>or</u>
consist of only slightly altered parent material below the mollic epipedon
-carbonates or soluble salts may have accumulated

Natrargids

Soils have one or more of the following characteristics:

-a natric horizon often within a few cm depth
-no petrocalcic horizon or duripan within 1 m depth
-carbonates are common throughout the profile
-carbonates and soluble salts may accumulate below the natric horizon
-salic, gypsic, or calcic horizons may be present
-developed mostly on near-level sediments of late-Pleistocene age

Torrifluvents

Soils have one or more of the following characteristics:

-no diagnostic horizons
-torric moisture regime, arid climates
-mean annual soil temperature is 8°C or higher
-organic carbon decreases irregularly with depth
-profile is at least 25 cm in depth
-alkaline or calcareous, sometimes saline
-developed on recent alluvial sediments
-slope less than 25 percent
-native plants of xerophytic shrubs and cacti
-flooded occasionally

Torriorthents

Soils have one or more of the following characteristics:

-no diagnostic horizons
-torric (aridic) moisture regime, <u>or</u>
conductivity of saturation extract greater than 2 mmho/cm in upper soil
-lithic contact less than 25 cm depth, <u>or</u>
loamy or finer texture in some horizon between 25 cm to 1 m, <u>or</u>
greater than 35 percent rock fragments within 1 m depth
-slope greater than 25 percent, <u>or</u>
organic carbon decreases regularly with depth to 0.2 percent within 1.25 m, <u>or</u>
lithic contact less than 25 cm depth
-not permanently saturated
-neutral or calcareous
-moderate to strong slopes, often on rock pediments
-vegetation sparse, mostly xerophytic shrubs, ephemeral grasses, and forbs, sometimes salt grass

APPENDIX F. Mineralogical Data of A- and C-Horizon Soil Samples from the Hanging Woman Creek Study Area

Minerals in whole soil samples, sand, silt, and clay fractions. Values in percent.

SAMPLE	TL QRTZ	TL PLAG	TL KSPAR	TL CALC	TL DOLM	TL CLAY	SA QRTZ	SA PLAG	SA KSPAR	SA CLAY
				Soil group no. 1						
11A	40.1	9.6	4.8	0.0	0.2	45.3	80.6	7.2	8.9	3.2
12A	46.9	7.7	8.5	0.9	2.1	35.9	74.0	8.1	8.3	9.6
13A	36.4	8.0	3.5	1.3	1.2	49.6	69.3	9.1	9.1	12.6
14A	46.5	3.4	7.0	0.0	0.0	43.1	72.7	5.7	10.7	10.9
				Soil group no. 2						
21A	35.7	9.3	3.6	4.6	2.6	44.3	72.5	7.7	11.0	8.8
22A	34.3	6.9	3.9	5.1	2.8	47.0	76.6	8.5	9.5	5.4
23A	30.0	6.5	2.6	6.9	2.8	51.1	68.2	8.6	8.2	15.0
24A	46.4	5.2	5.8	3.2	1.8	37.7	87.6	6.2	6.2	0.0
				Soil group no. 3						
31A	35.3	7.8	4.4	11.3	1.1	40.2	65.1	8.7	11.6	14.6
32A	32.3	11.0	2.2	10.7	3.9	39.9	65.5	18.5	3.2	12.8
33A	38.5	8.9	3.6	5.5	2.5	41.0	63.6	11.4	11.5	13.5
34A	45.0	5.7	9.0	6.7	1.3	32.4	79.2	6.8	8.6	5.4
				Soil group no. 4						
41A	55.0	4.2	7.2	0.1	0.0	33.5	74.8	9.2	10.5	5.5
42A	46.3	8.4	5.6	1.4	2.9	35.5	79.4	5.7	9.7	5.2
43A	49.9	11.1	8.9	0.2	2.7	27.3	76.3	7.5	7.8	8.4
44A	48.0	7.4	6.3	0.6	2.6	35.2	76.0	8.1	10.1	5.8

Appendix F

Minerals in whole soil samples, sand, silt, and clay fractions. Values in percent.-continued

SAMPLE	SI QRTZ	SI PLAG	SI KSPAR	SI CLAY	CL QRTZ	CL PLAG	CL KSPAR	CL CLAY
Soil group no. 1-continued								
11A	57.3	11.5	7.2	24.0	16.0	3.7	2.5	77.8
12A	66.5	10.7	8.9	14.9	23.5	3.5	4.7	68.3
13A	56.9	12.1	7.0	24.0	9.4	0.0	0.0	90.6
14A	60.4	10.5	10.6	18.6	12.2	5.4	0.0	82.0
Soil group no. 2-continued								
21A	54.1	12.9	6.2	26.8	11.3	4.2	0.0	66.9
22A	60.6	13.1	5.4	20.9	11.8	2.0	0.0	86.2
23A	48.9	12.9	2.0	36.2	16.7	8.1	0.0	75.2
24A	62.1	10.5	7.9	19.6	11.3	7.2	0.0	81.5
Soil group no. 3-continued								
31A	55.8	13.4	6.3	24.4	11.4	2.4	0.0	86.2
32A	54.4	15.6	6.1	23.9	9.6	4.8	8.2	77.4
33A	57.3	15.1	7.9	19.7	11.2	3.7	2.5	82.7
34A	62.5	13.9	6.2	17.4	18.2	0.0	3.6	78.1
Soil group no. 4-continued								
41A	63.4	11.3	7.8	17.5	13.4	2.6	3.6	80.4
42A	65.2	10.5	9.7	14.6	11.4	2.2	0.0	86.4
43A	60.3	13.0	8.5	18.3	15.1	2.4	0.0	82.5
44A	66.5	7.2	9.0	17.4	12.4	10.3	0.0	77.3

APPENDIX G. Chemical Data of A- and C-Horizon soil samples from the Hanging Woman Creek Study Area

Element composition of soil samples, A and C horizons

FIELD NO	SAMPLE	B ppm-S	Ba ppm-S	Be ppm-S	Co ppm-S	Cr ppm-S	Cu ppm-S	Ga ppm-S	La ppm-S	Mn ppm-S
				Soil group no. 1						
11A	187333	54.200	469.000	2.120	10.400	82.700	47.700	20.700	46.900	542.000
11C	187312	50.300	518.000	2.060	7.780	57.800	56.600	13.700	38.200	411.000
12A	187343	44.500	409.000	2.370	9.790	56.200	58.600	11.400	42.100	421.000
12C	187339	42.100	504.000	1.830	11.800	66.700	62.600	14.900	41.400	534.000
13A	187341	47.400	441.000	2.850	12.300	76.000	50.300	18.000	42.000	509.000
13C	187325	32.700	440.000	2.530	8.670	54.600	22.300	10.400	30.800	376.000
14A	187311	43.400	447.000	1.820	10.100	64.600	28.600	13.100	34.500	544.000
14C	187309	40.100	430.000	1.380	6.660	43.800	19.500	7.570	30.600	383.000
				Soil group no. 2						
21A	187315	42.300	542.000	2.880	10.700	67.200	34.600	12.700	34.400	662.000
21C	187346	50.300	502.000	1.830	10.200	73.600	31.400	17.700	37.000	794.000
22A	187353	55.300	495.000	2.290	11.400	86.100	52.600	20.200	38.800	735.000
22C	187352	51.000	512.000	2.380	15.600	74.500	52.400	17.500	33.000	1060.000
23A	187347	50.100	564.000	2.370	16.400	83.500	43.700	20.900	35.200	1100.000
23C	187351	52.800	662.000	2.710	15.400	85.300	48.500	21.800	36.300	1280.000
24A	187321	45.100	449.000	1.750	9.330	66.100	28.600	12.000	35.100	467.000
24C	187345	46.900	444.000	1.910	11.100	73.100	80.400	17.100	49.500	439.000
				Soil group no. 3						
31A	187306	33.500	379.000	0.950	7.310	66.000	25.300	8.020	22.600	364.000
31C	187348	34.500	536.000	1.700	8.290	68.300	35.000	14.500	31.200	454.000
32A	187334	39.000	475.000	2.430	12.000	75.500	35.700	14.800	35.600	543.000
32C	187349	49.500	477.000	1.830	10.300	78.500	38.100	15.000	38.200	673.000
33A	187329	41.000	458.000	2.130	12.400	79.100	43.200	14.600	39.200	546.000
33C	187330	44.900	491.000	3.200	13.300	87.200	64.900	17.400	43.300	714.000
34A	187340	42.100	464.000	1.830	11.500	49.600	31.600	12.300	38.700	526.000
34C	187308	35.100	563.000	1.390	8.810	49.000	23.000	9.170	33.300	445.000
				Soil group no. 4						
41A	187320	43.500	342.000	0.930	3.930	33.000	17.400	5.300	20.800	355.000
41C	187324	26.100	410.000	1.290	5.020	32.200	14.400	5.750	29.900	252.000
42A	187344	49.100	455.000	1.890	10.600	61.900	64.300	16.100	49.200	446.000
42C	187342	24.500	359.000	1.210	5.820	21.700	11.100	6.680	26.100	309.000
43A	187337	32.600	469.000	1.530	8.540	47.600	26.300	10.600	39.100	496.000
43C	187322	54.300	508.000	1.560	9.230	54.400	24.800	11.800	37.800	552.000
44A	187313	38.600	427.000	1.460	6.190	48.100	23.900	9.720	41.100	331.000
44C	187328	43.900	402.000	1.570	7.570	47.000	25.500	10.200	45.000	378.000

APPENDIX G

Element composition of soil samples, A and C horizons-continued

FIELD NO	SAMPLE	Mo ppm-S	Nb ppm-S	Ni ppm-S	Pb ppm-S	Sc ppm-S	Sr ppm-S	V ppm-S	Y ppm-S	Yb ppm-S
				Soil group no. 1-continued						
11A	187333	10.200	10.100	36.800	11.900	11.600	176.000	117.000	27.100	4.460
11C	187312	7.920	10.300	27.000	10.300	9.310	252.000	94.300	25.800	3.650
12A	187343	6.250	9.430	28.200	9.400	8.620	182.000	78.300	24.300	3.210
12C	187339	8.270	15.900	29.900	12.600	11.300	269.000	84.500	28.100	3.780
13A	187341	4.150	9.810	39.700	9.760	13.900	180.000	119.000	28.200	4.030
13C	187325	3.950	9.760	27.000	4.600	7.010	225.000	69.800	22.200	2.610
14A	187311	6.440	5.130	31.200	7.400	10.200	182.000	89.100	23.000	3.100
14C	187309	2.360	8.280	20.500	4.490	4.470	213.000	63.200	17.600	2.350
				Soil group no. 2-continued						
21A	187315	8.580	2.990	38.700	5.040	12.100	204.000	89.100	21.500	2.870
21C	187346	6.810	2.730	37.700	8.720	13.500	278.000	89.800	21.400	2.700
22A	187353	4.920	9.480	46.400	10.900	14.600	224.000	108.000	26.700	3.430
22C	187352	6.440	8.010	53.100	10.300	12.400	299.000	98.200	24.900	3.290
23A	187347	4.640	4.260	52.300	10.500	15.600	238.000	108.000	21.600	2.980
23C	187351	6.800	2.250	56.000	13.000	15.900	316.000	107.000	23.800	2.970
24A	187321	3.340	7.580	29.800	10.900	10.200	221.000	92.400	26.300	3.540
24C	187345	8.820	6.300	33.000	11.500	12.900	329.000	113.000	28.700	3.950
				Soil group no. 3-continued						
31A	187306	5.360	7.060	27.000	4.150	5.540	170.000	67.300	15.300	1.920
31C	187348	3.500	4.560	32.600	3.420	11.300	354.000	71.500	18.200	3.350
32A	187334	9.260	10.900	38.100	5.900	13.700	319.000	94.400	22.500	3.470
32C	187349	3.150	4.650	36.800	8.470	12.600	203.000	88.500	23.500	3.880
33A	187329	6.840	14.600	34.400	8.940	11.600	258.000	94.400	19.200	3.170
33C	187330	9.400	11.400	43.900	10.800	15.500	350.000	124.000	24.700	3.580
34A	187340	8.330	12.600	30.000	11.300	10.100	276.000	78.900	25.500	3.350
34C	187308	6.090	5.490	25.500	4.160	8.280	282.000	70.200	19.300	2.540
				Soil group no. 4-continued						
41A	187320	2.150L	7.170	13.600	2.820	3.790	141.000	49.400	19.400	1.970
41C	187324	5.700	5.440	13.800	2.930	4.410	157.000	47.500	15.400	1.690
42A	187344	6.470	12.100	30.000	11.400	11.100	242.000	93.900	29.200	4.040
42C	187342	2.090	8.300	13.300	4.680	4.060	143.000	39.600	16.900	2.270
43A	187337	5.800	8.400	24.900	8.120	9.070	195.000	69.500	24.900	3.080
43C	187322	4.180	3.830	28.000	7.340	8.440	200.000	77.600	38.200	3.560
44A	187313	5.430	12.900	22.000	4.410	7.800	163.000	71.800	27.100	3.300
44C	187328	6.230	8.370	23.200	8.110	8.500	186.000	72.000	26.400	3.800

APPENDIX G

Element composition of soil samples, A and C horizons-continued

FIELD NO	SAMPLE	Zr ppm-S	Al %	Si %	Ca %	Ti %	T-Fe %	K %	Mg %	Na %
				Soil group no. 1-continued						
11A	187333	347.000	6.060	29.694	1.093	0.351	2.507	2.061	0.989	0.824
11C	187312	310.000	5.494	28.493	2.583	0.304	2.365	1.815	1.116	0.861
12A	187343	319.000	5.226	30.302	1.650	0.289	2.323	1.907	0.935	0.764
12C	187339	389.000	5.170	29.320	2.291	0.285	2.436	1.786	1.176	0.898
13A	187341	294.000	6.611	27.684	1.088	0.337	3.030	1.965	1.013	0.601
13C	187325	331.000	5.341	27.497	4.125	0.289	2.726	1.659	1.333	0.645
14A	187311	261.000	6.188	30.788	0.381	0.303	2.580	1.945	0.609	0.564
14C	187309	310.000	4.759	30.348	2.962	0.261	2.072	1.665	0.941	0.571
				Soil group no. 2-continued						
21A	187315	246.000	5.716	26.445	3.346	0.292	3.240	1.653	1.267	0.720
21C	187346	223.000	5.298	23.108	5.580	0.325	3.330	1.740	2.171	0.809
22A	187353	269.000	5.806	27.221	3.042	0.362	2.786	1.880	1.267	0.631
22C	187352	285.000	5.478	27.880	3.165	0.331	2.892	1.745	1.478	0.749
23A	187347	247.000	5.865	24.693	3.786	0.338	3.356	1.848	1.496	0.586
23C	187351	231.000	5.690	24.679	3.685	0.331	3.746	1.845	1.749	0.712
24A	187321	300.000	5.494	29.727	2.436	0.284	2.597	1.684	0.983	0.571
24C	187345	404.000	5.637	28.404	2.763	0.301	2.436	1.664	1.182	0.631
				Soil group no. 3-continued						
31A	187306	165.000	5.076	26.660	5.084	0.287	2.479	1.441	1.242	0.824
31C	187348	243.000	4.503	25.015	6.246	0.306	2.230	1.339	1.876	1.061
32A	187334	293.000	5.155	25.576	5.530	0.288	2.765	1.394	1.586	0.875
32C	187349	325.000	4.667	28.203	3.415	0.320	2.459	1.496	1.104	0.757
33A	187329	279.000	5.690	27.268	3.321	0.300	2.747	1.601	1.345	0.920
33C	187330	288.000	5.886	23.693	3.296	0.344	3.233	1.727	1.906	1.143
34A	187340	392.000	4.727	28.180	4.721	0.252	2.715	1.545	0.929	0.534
34C	187308	314.000	4.276	28.133	4.936	0.261	2.637	1.562	1.152	0.549
				Soil group no. 4-continued						
41A	187320	292.000	4.478	32.709	0.823	0.247	1.742	1.818	0.579	0.690
41C	187324	237.000	4.578	32.956	2.005	0.225	1.618	1.689	0.669	0.816
42A	187344	504.000	5.399	28.586	1.770	0.282	2.343	1.857	1.049	0.913
42C	187342	273.000	3.091	35.312	1.412	0.168	1.260	1.616	0.470	0.705
43A	187337	391.000	4.871	31.073	1.762	0.257	2.116	1.809	0.850	0.594
43C	187322	485.000	4.496	31.105	1.860	0.257	2.086	1.682	0.899	0.638
44A	187313	370.000	4.558	30.778	1.730	0.267	1.943	1.763	0.959	0.861
44C	187328	335.000	4.770	30.353	2.103	0.274	2.035	1.793	1.055	0.824

Element composition of soil samples, A and C horizons-continued

FIELD NO	SAMPLE	F%	Sn ppm	Ge ppm	As ppm	Se ppm	T-C%	Orgnc C%	Crbnt C%	Hg ppm
Soil group no. 1-continued										
11A	187333	0.060	1.124	1.587	8.431	0.164	1.260	1.060	0.200	0.030
11C	187312	0.060	1.057	1.544	7.492	0.197	1.100	0.320	0.780	0.030
12A	187343	0.040	1.449	1.701	9.484	0.191	1.350	1.000	0.350	0.030
12C	187339	0.050	1.294	1.822	5.669	0.345	1.020	0.340	0.680	0.030
13A	187341	0.070	1.119	1.403	12.000	0.179	1.600	1.420	0.180	0.030
13C	187325	0.070	1.181	1.466	9.736	0.325	2.420	1.020	1.400	0.030
14A	187311	0.050	1.449	1.843	7.727	0.196	1.140	1.140	0.010L	0.020
14C	187309	0.050	1.460	1.648	9.237	0.111	1.590	1.140	0.450	0.030
Soil group no. 2-continued										
21A	187315	0.060	1.018	1.286	8.210	0.374	2.810	1.820	0.990	0.030
21C	187346	0.080	1.700	1.218	3.987	0.454	2.600	0.050	2.550	0.040
22A	187353	0.070	1.158	1.054	5.226	0.120	2.410	1.870	0.540	0.020
22C	187352	0.060	1.127	1.438	8.546	0.377	1.950	0.980	0.970	0.030
23A	187347	0.070	1.453	1.283	9.430	0.100L	2.150	1.020	1.130	0.040
23C	187351	0.080	1.082	1.305	13.150	0.219	1.810	0.530	1.280	0.040
24A	187321	0.050	1.558	1.507	8.809	0.281	1.540	0.790	0.750	0.030
24C	187345	0.060	1.349	1.586	7.712	0.354	1.370	0.520	0.850	0.040
Soil group no. 3-continued										
31A	187306	0.050	0.843	1.084	7.705	0.100L	2.430	1.240	1.190	0.030
31C	187348	0.070	1.267	1.060	5.012	0.100L	2.520	2.470	2.050	0.040
32A	187334	0.060	0.714	0.989	9.698	0.144	2.480	0.730	1.750	0.030
32C	187349	0.050	0.976	1.217	9.965	0.100L	2.300	1.410	0.890	0.010
33A	187329	0.060	0.709	0.826	3.923	0.299	1.880	0.870	1.010	0.040
33C	187330	0.080	1.128	0.785	3.500	0.287	1.600	0.370	1.230	0.040
34A	187340	0.050	1.976	1.620	10.350	0.286	2.600	1.280	1.320	0.030
34C	187308	0.050	1.193	1.237	7.739	0.168	2.120	0.780	1.340	0.030
Soil group no. 4-continued										
41A	187320	0.040	0.747	1.398	5.945	0.314	1.150	1.020	0.130	0.020
41C	187324	0.040	1.148	1.017	5.659	0.100L	0.940	0.350	0.590	0.020
42A	187344	0.060	1.166	0.948	5.073	0.100L	2.100	1.690	0.410	0.020
42C	187342	0.040	0.671	1.280	6.458	0.100L	0.710	0.450	0.260	0.020
43A	187337	0.050	1.606	1.592	7.953	0.100L	1.920	1.510	0.410	0.030
43C	187322	0.060	1.230	1.593	10.280	0.149	1.390	0.800	0.590	0.030
44A	187313	0.050	0.692	1.291	7.090	0.213	2.130	1.580	0.550	0.020
44C	187328	0.050	1.259	1.839	8.814	0.364	1.580	0.950	0.630	0.040

Element composition of soil samples, A and C horizons-continued

FIELD NO	SAMPLE	Li ppm	Rb ppm	Zn ppm	Th ppm	U ppm	ph
				Soil group no. 1-continued			
11A	187333	28.000	95.000	94.000	9.380	2.940	8.200
11C	187312	28.000	95.000	80.000	9.520	3.970	7.500
12A	187343	24.000	85.000	79.000	9.190	2.830	7.800
12C	187339	26.000	80.000	81.000	10.580	3.780	8.600
13A	187341	29.000	95.000	101.000	10.090	2.930	8.100
13C	187325	25.000	75.000	82.000	8.510	3.380	8.400
14A	187311	30.000	105.000	93.000	13.560	3.740	7.000
14C	187309	25.000	80.000	69.000	11.080	3.100	8.300
				Soil group no. 2-continued			
21A	187315	25.000	75.000	91.000	9.440	3.090	8.100
21C	187346	29.000	70.000	92.000	8.990	4.190	7.800
22A	187353	29.000	79.000	98.000	9.760	2.800	8.200
22C	187352	26.000	74.000	94.000	9.640	2.990	8.800
23A	187347	30.000	81.000	101.000	11.860	3.110	7.800
23C	187351	31.000	88.000	105.000	11.730	4.170	8.200
24A	187321	29.000	80.000	83.000	10.930	3.470	8.100
24C	187345	28.000	80.000	83.000	11.590	4.570	9.100
				Soil group no. 3-continued			
31A	187306	22.000	65.000	74.000	7.770	2.680	8.500
31C	187348	23.000	53.000	75.000	10.450	3.060	8.300
32A	187334	20.000	60.000	82.000	8.380	2.450	8.700
32C	187349	20.000	46.000	78.000	9.680	2.520	8.300
33A	187329	21.000	60.000	81.000	8.700	2.850	8.100
33C	187330	29.000	80.000	97.000	9.480	3.790	8.400
34A	187340	22.000	70.000	74.000	9.960	2.790	8.300
34C	187308	24.000	70.000	70.000	10.890	3.090	8.400
				Soil group no. 4-continued			
41A	187320	22.000	80.000	65.000	11.130	2.690	8.600
41C	187324	19.000	75.000	58.000	9.530	2.880	8.700
42A	187344	26.000	85.000	86.000	9.080	3.860	8.200
42C	187342	13.000	60.000	42.000	6.900	2.380	8.700
43A	187337	23.000	80.000	72.000	10.140	2.780	8.200
43C	187322	25.000	75.000	72.000	9.200	3.530	8.200
44A	187313	23.000	85.000	70.000	11.250	3.280	7.900
44C	187328	24.000	80.000	72.000	11.760	4.100	8.300

APPENDIX H.

Data for defining moisture relations in soils

DEPTH	RETENTION FORCE		VOLUME WEIGHT	AVERAGE VOLUME WEIGHT	SOIL MOISTURE	MOISTURE RETENTION CAPABILITY	ADSORPTION CAPACITY	VOID MOISTURE CAPACITY	SOIL MOISTURE	VOID MOISTURE CAPACITY	PERMEABILITY
M	G/SQCM	PF	G/CC	G/CC	%	%	%	%	MOLECULAR LAYERS OF WATER	MOLECULAR LAYERS OF WATER	CM/HR

HANG SITE 1 DATE: 9/21/76 SAMPLE NO. 1

0.10	30728.	4.49	1.38	1.38	9.91	22.01	35.21	34.81	4.5	15.8	1.9
0.20	25544.	4.41	1.34	1.35	8.40	17.83	28.54	36.32	4.7	20.4	2.1
0.30	27751.	4.44	1.33	1.30	7.14	15.46	24.74	38.91	4.6	25.2	2.4
0.40	12120.	4.08	1.24	1.31	7.43	13.41	21.46	38.52	5.5	28.7	2.6
0.50	10852.	4.04	1.36	1.35	5.77	10.20	16.31	36.49	5.7	35.8	3.1
0.60	10910.	4.04	1.44	1.39	5.07	8.95	14.33	34.26	5.7	38.3	3.2
0.70	5780.	3.76	1.37	1.52	6.43	10.10	16.16	28.27	6.4	29.0	2.6
0.80	1391.	3.14	1.74	1.47	5.03	6.32	10.12	30.38	7.9	48.0	3.8
0.90	210.	2.32	1.30	1.46	7.89	7.85	12.56	30.67	10.1	39.1	3.3
1.00	157.	2.20	1.35	1.43	8.93	8.61	13.77	32.11	10.4	37.3	3.2
1.10	157.	2.19	1.65	1.72	8.57	8.26	13.21	20.33	10.4	24.6	2.4
1.20	137.	2.14	2.17	1.95	5.45	5.18	8.29	13.45	10.5	26.0	2.5
1.30	143.	2.16	2.04	1.92	7.05	6.73	10.77	14.29	10.5	21.2	2.2
1.40	128.	2.11	1.55	1.89	12.52	11.82	18.91	15.11	10.6	12.8	1.7
1.50	163.	2.21	2.08	1.88	8.94	8.55	13.68	15.46	10.3	18.1	[illegible]
1.60	144.	2.16	2.01	2.03	8.29	7.91	12.65	11.59	10.5	14.6	1.8
1.70	96.	1.98	1.99	1.97	9.20	8.42	13.48	12.93	10.9	15.4	1.8
1.80	85.	1.93	1.92	1.98	7.50	6.78	10.85	12.78	11.1	18.8	2.1
1.90	51.	1.71	2.02	1.94	9.80	8.44	13.50	13.76	11.6	16.3	1.9
2.00	51.	1.70	1.89	1.96	9.86	8.47	13.56	13.29	11.6	15.7	1.9
2.10	42.	1.62	1.97	2.03	13.47	11.39	18.20	11.49	11.8	10.1	1.5
2.20	46.	1.67	2.24	2.09	11.87	10.12	16.20	10.05	11.7	9.9	1.5
2.30	16.	1.20	2.06	2.07	16.58	12.82	20.51	10.53	12.9	8.2	1.4
2.40	22.	1.34	1.91	1.93	15.92	15.84	25.35	13.97	12.6	8.8	1.4
2.50	35.	1.55	1.83	1.88	12.40	10.30	16.48	15.40	12.0	14.9	1.8
2.60	16.	1.21	1.91	1.82	20.01	15.50	24.81	17.09	12.9	11.0	1.5
2.70	15.	1.16	1.74	1.68	21.89	16.81	26.89	21.67	13.0	12.9	1.7
2.80	8.	0.89	1.40	1.77	20.74	15.10	24.15	18.80	13.7	12.4	1.7
2.90	9.	0.97	2.17	1.76	21.21	15.71	25.13	19.17	13.5	12.2	1.6
3.00	5.	0.71	1.70	1.66	20.20	14.24	22.79	22.35	14.2	15.7	1.9
3.10	6.	0.74	1.12	1.12	17.50	12.42	19.87	51.17	14.1	41.2	3.4

HANG SITE 2 DATE: 9/21/76 SAMPLE NO. 1

0.10	136190.	5.13	1.23	1.23	2.84	9.98	15.96	43.41	2.8	43.5	3.5
0.20	91837.	4.96	1.36	1.35	3.30	10.05	16.08	35.21	3.3	36.0	3.1
0.30	64127.	4.81	1.47	1.55	3.40	9.22	14.75	26.89	3.7	29.2	2.7
0.40	52954.	4.72	1.82	1.55	3.58	9.19	14.70	26.81	3.9	29.2	2.7
0.50	44619.	4.65	1.36	1.57	3.29	8.05	12.87	25.91	4.1	32.2	2.9
0.60	61502.	4.79	1.53	1.55	3.87	10.36	16.57	26.63	3.7	25.7	2.5
0.70	49160.	4.69	1.77	1.72	4.47	11.23	17.97	20.49	4.0	18.2	2.0
0.80	43601.	4.64	1.85	1.74	5.58	13.56	21.70	19.63	4.1	14.5	1.8
0.90	49855.	4.70	1.61	1.67	6.56	16.54	26.47	22.31	4.0	13.5	1.7
1.00	41390.	4.62	1.53	1.63	4.77	11.42	18.27	23.55	4.2	20.6	2.2
1.10	34127.	4.53	1.75	1.51	6.36	14.49	23.18	28.70	4.4	19.8	2.1
1.20	41524.	4.62	1.23	1.56	8.02	19.24	30.78	26.22	4.2	13.6	1.7
1.30	20533.	4.31	1.71	1.42	8.79	17.74	28.38	32.46	5.0	18.3	2.0
1.40	16355.	4.21	1.34	1.50	7.93	15.24	24.38	28.82	5.2	18.9	2.1
1.50	17998.	4.25	1.46	1.31	7.85	15.40	24.64	38.63	5.1	25.1	2.4
1.60	12411.	4.09	1.13	1.52	8.27	15.00	23.99	27.93	5.5	18.6	2.0
1.70	13323.	4.12	1.98	1.45	6.36	11.71	18.73	31.37	5.4	26.8	2.5
1.80	12312.	4.09	1.24	1.46	6.50	11.78	18.65	29.92	5.5	25.4	2.4
1.90	9098.	3.96	1.22	1.22	6.67	11.73	18.77	44.00	5.9	37.5	3.2
2.00	10962.	4.04	1.21	1.41	7.52	13.31	21.29	33.01	5.7	24.8	2.4
2.10	8822.	3.95	1.81	1.40	8.06	13.67	21.88	33.50	5.9	24.5	2.4
2.20	7366.	3.87	1.19	1.71	7.62	12.50	20.00	20.70	6.1	16.6	1.9
2.30	9876.	3.99	2.14	1.49	7.65	13.26	21.21	29.21	5.8	22.0	2.2
2.40	8526.	3.93	1.15	1.15	7.99	13.48	21.57	48.92	5.9	36.3	3.1

Data for defining moisture relations in soils--Continued

MANG SITE 3 DATE: 9/21/76 SAMPLE NO. 1

M DEPTH	RETENTION FORCE		VOLUME WEIGHT	AVERAGE VOLUME WEIGHT	SOIL MOISTURE	MOISTURE RETENTION CAPABILITY	ADSORPTION CAPACITY	VOID MOISTURE CAPACITY	SOIL MOISTURE	VOID MOISTURE CAPACITY	PERMEABILITY
M	G/SQCM	PF	G/CC	G/CC	%	%	%	%	MOLECULAR LAYERS OF WATER	MOLECULAR LAYERS OF WATER	CM/HR
0.10	345131.	5.54	1.18	1.18	7.24	39.89	63.82	47.84	1.8	11.8	1.6
0.20	106788.	5.03	1.62	1.40	9.41	30.19	48.30	33.68	3.1	11.2	1.5
0.30	63783.	4.80	1.40	1.56	7.57	20.49	32.78	26.56	3.7	13.0	1.7
0.40	39273.	4.59	1.64	1.51	8.64	20.41	32.66	28.50	4.2	14.0	1.8
0.50	9797.	3.99	1.48	1.50	12.55	21.72	34.75	28.81	5.8	13.3	1.7
0.60	4840.	3.68	1.38	1.41	15.72	23.96	38.34	33.30	6.6	13.9	1.8
0.70	5266.	3.72	1.36	1.36	14.76	22.63	36.57	35.64	6.5	15.6	1.9
0.80	6614.	3.82	1.35	1.30	12.15	19.56	31.29	39.18	6.2	20.0	2.1
0.90	4755.	3.68	1.19	1.31	11.75	17.66	28.57	38.60	6.6	21.6	2.2
1.00	7286.	3.86	1.39	1.37	9.27	15.17	24.28	35.12	6.1	23.1	2.3
1.10	7161.	3.85	1.54	1.39	8.87	14.47	23.16	34.37	5.1	23.7	2.3
1.20	14338.	4.16	1.24	1.55	9.11	17.01	27.22	26.76	5.4	15.7	1.9
1.30	4796.	3.68	1.89	1.48	7.95	12.10	19.36	29.65	6.6	24.7	2.4
1.40	7187.	3.86	1.32	1.52	5.48	8.95	14.32	20.28	6.1	31.6	2.8
1.50	9773.	3.99	1.34	1.35	9.75	16.87	26.99	35.24	5.8	21.5	2.2
1.60	6747.	3.83	1.39	1.74	9.90	15.98	25.58	19.58	5.2	12.3	1.7
1.70	4955.	3.70	2.50	1.81	9.96	15.24	24.38	17.[illegible]7	6.5	11.6	1.6
1.80	2520.	3.40	1.53	1.86	14.12	19.38	31.00	15.90	7.3	8.2	1.4
1.90	4446.	3.65	1.56	1.51	14.19	21.32	34.12	28.37	6.7	13.3	1.7
2.00	2257.	3.35	1.45	1.45	14.60	19.97	31.95	31.02	7.4	15.5	1.8
2.10	2095.	3.32	1.35	1.39	15.49	22.01	35.22	34.00	7.5	15.4	1.8
2.20	2891.	3.46	1.38	1.47	13.36	18.75	30.00	30.48	7.1	16.3	1.9
2.30	2788.	3.45	1.66	1.52	12.08	16.63	26.53	27.66	7.2	16.5	1.9
2.40	3293.	3.52	1.53	1.53	8.04	11.50	18.41	27.72	7.0	24.1	2.4

MANG SITE 4 DATE: 9/21/76 SAMPLE NO. 1

M DEPTH	RETENTION FORCE		VOLUME WEIGHT	AVERAGE VOLUME WEIGHT	SOIL MOISTURE	MOISTURE RETENTION CAPABILITY	ADSORPTION CAPACITY	VOID MOISTURE CAPACITY	SOIL MOISTURE	VOID MOISTURE CAPACITY	PERMEABILITY
M	G/SQCM	PF	G/CC	G/CC	%	%	%	%	MOLECULAR LAYERS OF WATER	MOLECULAR LAYERS OF WATER	CM/HR
0.10	134229.	5.13	1.10	1.10	2.60	9.07	14.51	53.08	2.9	58.5	4.5
0.20	123694.	5.09	1.61	1.46	5.21	17.61	28.18	30.99	3.0	17.6	2.0
0.30	106957.	5.03	1.65	1.65	5.46	17.52	28.03	22.91	3.1	13.1	1.7
0.40	113688.	5.06	1.66	1.66	3.46	11.35	18.16	22.39	3.0	19.7	2.1
0.50	79418.	4.90	1.66	1.70	2.62	7.61	17.17	21.14	3.4	27.8	2.6
0.60	57415.	4.76	1.76	1.70	3.45	9.06	14.50	21.06	3.8	23.2	2.3
0.70	67056.	4.83	1.69	1.71	3.07	8.43	13.49	20.69	3.6	24.5	2.4
0.80	48306.	4.68	1.69	1.64	2.89	7.23	11.57	23.34	4.0	32.3	2.9
0.90	41989.	4.62	1.53	1.52	3.34	8.04	12.87	27.85	4.2	34.6	3.0
1.00	20207.	4.31	1.35	1.45	5.66	11.38	18.21	31.37	5.0	27.5	2.6
1.10	25126.	4.40	1.46	1.50	5.35	11.30	18.09	29.06	4.7	25.7	2.5
1.20	27990.	4.45	1.68	1.65	8.39	18.20	29.13	22.88	4.6	12.6	1.7
1.30	18895.	4.28	1.81	1.44	9.14	18.11	28.97	31.63	5.0	17.5	2.0
1.40	17426.	4.24	0.83	1.52	17.12	23.60	37.77	28.21	5.1	12.0	1.6
1.50	21608.	4.33	1.91	1.31	14.11	28.81	46.10	38.60	4.9	13.4	1.7
1.60	15951.	4.20	1.19	1.71	11.98	27.89	35.63	20.88	5.2	9.1	1.5
1.70	13646.	4.14	2.02	1.53	6.86	12.68	20.28	27.63	5.4	21.8	2.2
1.80	14805.	4.17	1.38	1.62	5.09	9.57	15.30	23.84	5.3	24.9	2.4
1.90	10967.	4.04	1.47	1.42	4.82	8.54	13.66	32.66	5.7	38.3	3.2
2.00	13261.	4.12	1.41	1.47	3.57	6.55	10.49	30.43	5.4	46.4	3.7
2.10	12215.	4.09	1.52	1.42	5.07	9.17	14.68	32.52	5.5	35.5	3.1
2.20	10808.	4.03	1.34	1.50	5.33	9.41	15.06	29.07	5.7	30.9	2.8
2.30	7353.	3.87	1.63	1.49	4.20	6.89	11.03	29.19	6.1	42.3	3.5
2.40	5938.	3.77	1.51	1.51	3.96	6.25	9.99	28.53	6.3	45.7	3.7

Data for defining moisture relations in soils--Continued

HANG SITE 5 DATE: 9/21/76 SAMPLE NO. 1

DEPTH (M)	RETENTION FORCE (G/SQCM)	PF	VOLUME WEIGHT (G/CC)	AVERAGE VOLUME WEIGHT (G/CC)	SOIL MOISTURE (%)	MOISTURE RETENTION CAPABILITY (%)	ADSORPTION CAPACITY (%)	VOID MOISTURE CAPACITY (%)	SOIL MOISTURE (MOLECULAR LAYERS OF WATER)	VOID MOISTURE CAPACITY (MOLECULAR LAYERS OF WATER)	PERMEABILITY (CM/HR)
0.10	524698.	5.72	1.11	1.11	5.19	38.49	61.58	52.15	1.3	13.5	1.7
0.20	53524.	4.73	1.21	1.25	7.55	19.42	31.07	42.19	3.9	21.7	2.2
0.30	61449.	4.79	1.43	1.34	7.82	20.95	33.52	35.90	3.7	17.6	2.0
0.40	51766.	4.71	1.38	1.40	7.91	20.15	32.25	33.57	3.9	16.7	1.9
0.50	32389.	4.51	1.40	1.34	8.05	18.11	28.97	37.15	4.4	20.5	2.2
0.60	44834.	4.65	1.23	1.33	7.90	19.34	30.94	37.36	4.1	19.3	2.1
0.70	52621.	4.72	1.37	1.32	7.65	19.58	31.32	38.27	3.9	19.5	2.1
0.80	36810.	4.57	1.35	1.44	8.52	19.79	31.67	31.73	4.3	16.0	1.9
0.90	22046.	4.34	1.60	1.47	9.92	20.35	32.55	30.24	4.9	14.9	1.8
1.00	13917.	4.14	1.46	1.45	10.96	20.36	32.57	31.42	5.4	15.4	1.8
1.10	11565.	4.06	1.27	1.50	12.63	22.58	36.13	28.85	5.6	12.8	1.7
1.20	10414.	4.02	1.77	1.53	12.16	21.29	34.07	27.44	5.7	12.9	1.7
1.30	7769.	3.89	1.56	1.54	12.24	20.29	32.46	27.16	6.0	13.4	1.7
1.40	4024.	3.60	1.29	1.56	13.20	19.50	31.20	26.39	6.8	13.5	1.7
1.50	6820.	3.83	1.83	1.53	13.05	21.12	33.89	27.58	6.2	13.1	1.7
1.60	7327.	3.86	1.47	1.53	13.19	21.62	34.59	23.66	6.1	12.9	1.6
1.70	5543.	3.74	1.59	1.57	13.25	20.66	33.06	25.79	6.4	12.5	1.7
1.80	11613.	4.06	1.66	1.67	13.45	24.07	38.50	22.12	5.6	9.2	1.5
1.90	8316.	3.92	1.76	1.73	12.62	21.17	33.87	20.21	6.0	9.5	1.5
2.00	9882.	3.99	1.75	1.75	12.46	21.64	34.62	19.37	5.8	9.0	1.5
2.10	6366.	3.80	1.74	1.69	13.91	22.23	35.57	21.49	6.3	9.7	1.5
2.20	7849.	3.89	1.58	1.76	13.32	22.12	35.40	19.15	6.0	8.7	1.4
2.30	13457.	4.13	1.96	1.80	13.02	24.01	38.42	17.69	5.4	7.4	1.4
2.40	9309.	3.97	1.86	1.88	13.43	23.03	36.85	15.55	5.8	6.8	1.3

HANG SITE 6 DATE: 9/21/76 SAMPLE NO. 1

DEPTH (M)	RETENTION FORCE (G/SQCM)	PF	VOLUME WEIGHT (G/CC)	AVERAGE VOLUME WEIGHT (G/CC)	SOIL MOISTURE (%)	MOISTURE RETENTION CAPABILITY (%)	ADSORPTION CAPACITY (%)	VOID MOISTURE CAPACITY (%)	SOIL MOISTURE (MOLECULAR LAYERS OF WATER)	VOID MOISTURE CAPACITY (MOLECULAR LAYERS OF WATER)	PERMEABILITY (CM/HR)
0.10	171836.	5.24	1.15	1.15	5.57	21.52	34.44	49.18	2.6	22.9	2.3
0.20	68491.	4.84	1.43	1.45	8.60	23.80	38.07	31.09	3.6	13.1	1.7
0.30	39455.	4.60	1.78	1.60	10.12	23.94	38.31	24.69	4.2	10.3	1.5
0.40	56799.	4.75	1.60	1.63	9.73	25.46	40.73	23.55	3.8	9.2	1.5
0.50	40436.	4.61	1.52	1.61	8.90	21.20	33.92	24.31	4.2	11.5	1.6
0.60	55934.	4.75	1.72	1.57	9.64	25.12	40.19	26.07	3.8	10.4	1.5
0.70	50537.	4.70	1.46	1.52	10.08	25.50	40.81	28.26	4.0	11.1	1.6
0.80	35646.	4.55	1.35	1.44	9.23	21.27	34.04	30.01	4.3	14.1	1.8
0.90	39066.	4.59	1.60	1.45	9.21	21.73	34.77	31.16	4.2	14.3	1.6
1.00	50336.	4.70	1.39	1.56	8.84	22.34	35.75	26.39	4.0	11.8	1.6
1.10	46193.	4.66	1.69	1.63	8.54	21.08	33.73	23.47	4.1	11.1	1.6
1.20	63680.	4.80	1.83	1.65	7.68	20.78	33.24	22.72	3.7	10.9	1.6
1.30	42515.	4.63	1.45	1.65	9.19	22.17	35.47	22.95	4.1	10.4	1.5
1.40	25988.	4.41	1.67	1.57	8.60	18.34	29.35	26.16	4.7	14.3	1.8
1.50	28915.	4.46	1.58	1.57	7.82	17.11	27.37	25.79	4.6	15.1	1.8
1.60	14151.	4.15	1.46	1.48	7.05	13.13	21.01	29.97	5.4	22.8	2.3

HANG SITE 7 DATE: 9/21/76 SAMPLE NO. 1

DEPTH (M)	RETENTION FORCE (G/SQCM)	PF	VOLUME WEIGHT (G/CC)	AVERAGE VOLUME WEIGHT (G/CC)	SOIL MOISTURE (%)	MOISTURE RETENTION CAPABILITY (%)	ADSORPTION CAPACITY (%)	VOID MOISTURE CAPACITY (%)	SOIL MOISTURE (MOLECULAR LAYERS OF WATER)	VOID MOISTURE CAPACITY (MOLECULAR LAYERS OF WATER)	PERMEABILITY (CM/HR)
0.10	357552.	5.55	1.31	1.31	4.30	24.25	38.80	38.78	1.8	16.0	1.9
0.20	170091.	5.23	1.47	1.40	6.37	24.48	39.16	33.76	2.6	13.8	1.7
0.30	98676.	4.99	1.42	1.50	7.00	21.82	34.92	28.83	3.2	13.2	1.7
0.40	67032.	4.83	1.62	1.46	6.25	17.18	27.49	30.77	3.6	17.9	2.0
0.50	67973.	4.83	1.34	1.52	6.39	17.64	28.22	28.11	3.6	15.9	1.9
0.60	80704.	4.91	1.59	1.48	5.82	16.96	27.14	29.90	3.4	17.6	2.0
0.70	45553.	4.66	1.50	1.51	5.47	13.44	21.51	28.63	4.1	21.3	2.2
0.80	52565.	4.72	1.43	1.49	5.87	15.02	24.04	29.35	3.9	19.5	2.1
0.90	19485.	4.29	1.55	1.49	7.09	14.14	22.62	29.60	5.0	20.9	2.2
1.00	11503.	4.06	1.48	1.50	8.99	16.07	25.71	28.95	5.6	18.0	2.0
1.10	6275.	3.80	1.47	1.48	9.79	15.60	24.96	30.06	6.3	19.3	2.1
1.20	3814.	3.58	1.47	1.49	10.12	14.83	23.72	29.38	6.8	19.8	2.1
1.30	3220.	3.51	1.53	1.60	12.56	17.93	28.69	24.63	7.0	13.7	1.7
1.40	3024.	3.48	1.61	1.84	14.70	20.75	33.20	16.66	7.1	8.0	1.6
1.50	1012.	3.01	2.18	1.84	8.75	10.54	16.86	16.59	8.3	15.8	1.9
1.60	27920.	4.45	1.53	1.53	12.84	27.85	44.56	27.50	4.6	9.9	1.5

HANG SITE 8 DATE: 9/21/76 SAMPLE NO. 1

H DEPTH (M)	RETENTION FORCE (G/SQCM)	RETENTION FORCE (PF)	VOLUME WEIGHT (G/CC)	AVERAGE VOLUME WEIGHT (G/CC)	SOIL MOISTURE (%)	MOISTURE RETENTION CAPABILITY (%)	ADSORPTION CAPACITY (%)	VOID MOISTURE CAPACITY (%)	SOIL MOISTURE (MOLECULAR LAYERS OF WATER)	VOID MOISTURE CAPACITY (MOLECULAR LAYERS OF WATER)	PERMEABILITY (CM/HR)
0.10	88001.	4.94	1.19	1.19	4.38	13.15	21.04	46.09	3.3	35.1	3.4
0.20	17963.	4.25	1.44	1.35	8.16	16.00	25.59	36.37	5.1	22.7	2.3
0.30	15289.	4.18	1.42	1.48	10.86	20.57	32.91	29.78	5.3	14.5	1.8
0.40	7560.	3.88	1.59	1.57	10.53	17.36	27.78	26.04	6.1	15.0	1.8
0.50	3995.	3.60	1.70	1.76	10.95	16.16	25.85	19.03	6.8	11.8	1.6
0.60	1810.	3.26	2.00	1.89	15.53	20.29	32.47	15.15	7.7	7.5	1.4
0.70	2213.	3.35	1.94	2.00	14.75	19.85	31.76	12.22	7.4	6.2	1.3
0.80	1876.	3.27	2.03	1.99	15.10	19.63	31.73	12.55	7.6	6.3	1.3
0.90	1393.	3.14	1.96	1.92	15.80	19.88	31.81	14.25	7.9	7.2	1.3
1.00	937.	2.97	1.78	1.78	18.22	21.73	34.76	18.40	8.4	8.5	1.4
1.10	1406.	3.15	1.60	1.79	22.19	27.97	44.75	18.26	7.9	6.5	1.3
1.20	2924.	3.47	1.97	1.78	19.32	27.13	43.42	18.39	7.1	6.7	1.3
1.30	5202.	3.72	1.78	1.90	18.73	28.90	46.24	14.92	6.5	5.2	1.2
1.40	3602.	3.56	1.95	1.82	19.78	28.71	45.93	17.08	6.9	5.9	1.3
1.50	4487.	3.65	1.75	1.84	20.39	30.68	49.09	16.63	6.6	5.4	1.2
1.60	3261.	3.51	1.82	1.82	20.73	29.61	47.38	17.12	7.0	5.8	1.3

HANG SITE 9 DATE: 9/21/76 SAMPLE NO. 1

H DEPTH (M)	RETENTION FORCE (G/SQCM)	RETENTION FORCE (PF)	VOLUME WEIGHT (G/CC)	AVERAGE VOLUME WEIGHT (G/CC)	SOIL MOISTURE (%)	MOISTURE RETENTION CAPABILITY (%)	ADSORPTION CAPACITY (%)	VOID MOISTURE CAPACITY (%)	SOIL MOISTURE (MOLECULAR LAYERS OF WATER)	VOID MOISTURE CAPACITY (MOLECULAR LAYERS OF WATER)	PERMEABILITY (CM/HR)
0.10	217623.	5.34	1.17	1.17	7.05	30.29	48.47	47.83	2.3	15.8	1.9
0.20	38864.	4.59	1.44	1.47	12.53	29.52	47.23	30.50	4.2	10.3	1.5
0.30	15841.	4.20	1.38	1.46	14.43	27.52	44.04	29.70	5.2	10.8	1.6
0.40	7887.	3.90	1.22	1.23	17.54	29.15	46.64	43.75	6.0	15.0	1.8
0.50	11094.	4.05	1.08	1.25	19.11	33.90	54.23	41.95	5.6	12.4	1.7
0.60	5489.	3.74	1.47	1.31	22.18	34.55	55.28	38.63	6.4	11.2	1.6
0.70	40917.	4.61	1.38	1.46	16.39	39.16	62.66	30.73	4.2	7.8	1.4
0.80	5288.	3.72	1.53	1.51	26.64	41.22	65.95	28.51	6.5	6.9	1.3
0.90	2698.	3.46	1.61	1.62	24.08	33.77	54.03	24.16	7.1	7.2	1.3
1.00	2458.	3.39	1.70	1.61	17.94	24.52	39.23	24.32	7.3	9.9	1.5
1.10	3934.	3.59	1.52	1.72	16.20	26.80	42.88	20.39	6.8	7.6	1.4
1.20	4485.	3.65	1.44	1.84	17.84	26.85	42.94	16.74	6.6	6.2	1.3
1.30	3142.	3.50	2.05	1.97	17.49	24.83	39.73	13.15	7.0	5.3	1.2
1.40	8506.	3.93	1.91	2.03	17.39	29.31	46.89	11.45	5.9	3.9	1.1
1.50	5058.	3.70	2.14	1.95	16.47	25.29	40.47	13.44	6.5	5.3	1.2
1.60	5731.	3.76	1.81	1.81	16.47	25.85	41.35	17.45	6.4	6.8	1.3

HANG SITE 10 DATE: 9/21/76 SAMPLE NO. 1

H DEPTH (M)	RETENTION FORCE (G/SQCM)	RETENTION FORCE (PF)	VOLUME WEIGHT (G/CC)	AVERAGE VOLUME WEIGHT (G/CC)	SOIL MOISTURE (%)	MOISTURE RETENTION CAPABILITY (%)	ADSORPTION CAPACITY (%)	VOID MOISTURE CAPACITY (%)	SOIL MOISTURE (MOLECULAR LAYERS OF WATER)	VOID MOISTURE CAPACITY (MOLECULAR LAYERS OF WATER)	PERMEABILITY (CM/HR)
0.10	172896.	5.24	1.26	1.26	3.75	14.50	23.20	41.35	2.6	28.5	2.6
0.20	36674.	4.56	1.75	1.67	6.31	14.64	23.42	22.02	4.3	15.0	1.8
0.30	46613.	4.67	2.00	1.74	7.14	17.67	28.27	19.83	4.0	11.2	1.6
0.40	12384.	4.09	1.46	1.95	9.20	16.69	26.70	13.64	5.5	8.2	1.4
0.50	3956.	3.60	2.38	1.90	11.06	16.30	26.08	14.86	6.8	9.1	1.5
0.60	4131.	3.62	1.87	2.05	12.46	18.49	29.59	11.11	6.7	6.0	1.3
0.70	4594.	3.66	1.90	1.87	12.31	18.60	29.76	15.80	6.6	8.5	1.4
0.80	3475.	3.54	1.84	1.80	12.61	18.19	29.11	17.95	6.9	9.9	1.5
0.90	4885.	3.67	1.65	1.76	11.67	17.82	28.51	19.18	6.6	10.8	1.6
1.00	2325.	3.37	1.78	1.67	17.28	23.42	37.47	22.12	7.4	9.4	1.5
1.10	1854.	3.27	1.53	1.72	19.64	25.74	41.19	20.53	7.6	8.0	1.4
1.20	3394.	3.53	1.79	1.71	19.74	28.37	45.40	20.87	7.0	7.4	1.4
1.30	5691.	3.76	1.75	1.73	22.42	35.14	56.22	20.04	6.4	5.7	1.3
1.40	1713.	3.23	1.65	1.73	24.22	31.39	50.23	20.02	7.7	6.4	1.3
1.50	5380.	3.73	1.79	1.69	22.25	34.54	55.26	21.46	6.4	6.2	1.3
1.60	4564.	3.66	1.62	1.62	22.92	34.59	55.34	23.88	6.6	6.9	1.3

Data for defining moisture relations in soils--Continued

M DEPTH	RETENTION FORCE		VOLUME WEIGHT	AVERAGE VOLUME WEIGHT	SOIL MOISTURE	MOISTURE RETENTION CAPABILITY	ADSORPTION CAPACITY	VOID MOISTURE CAPACITY	SOIL MOISTURE	VOID MOISTURE CAPACITY	PERMEABILITY
M	G/SQCM	PF	G/CC	G/CC	%	%	%	%	MOLECULAR LAYERS OF WATER	MOLECULAR LAYERS OF WATER	CM/HR
HANG SITE 12 DATE: 9/21/76 SAMPLE NO. 1											
0.10	357682.	5.55	1.21	1.21	4.29	24.17	38.68	45.07	1.8	18.6	2.0
0.20	134772.	5.13	1.48	1.43	11.50	40.21	64.33	31.97	2.9	8.0	1.4
0.30	69756.	4.84	1.62	1.57	10.90	30.33	48.53	25.81	3.6	8.5	1.4
0.40	74447.	4.87	1.63	1.70	10.75	30.53	48.84	21.13	3.5	6.9	1.3
0.50	62270.	4.79	1.86	1.78	11.09	29.81	47.70	18.61	3.7	6.2	1.3
0.60	52389.	4.72	1.64	1.73	12.04	30.78	49.25	20.12	3.9	6.5	1.3
0.70	22904.	4.36	1.49	1.66	12.85	26.60	42.56	22.39	4.8	8.4	1.4
0.80	13605.	4.13	1.66	1.55	14.92	27.57	44.11	26.66	5.4	9.7	1.5
0.90	3115.	3.49	1.51	1.57	17.25	24.46	39.14	26.07	7.1	10.7	1.6
1.00	1442.	3.16	1.53	1.52	16.88	21.35	34.16	28.08	7.9	13.2	1.7
1.10	1800.	3.26	1.52	1.48	12.69	16.56	26.50	29.72	7.7	17.9	2.0
1.20	540.	2.73	1.40	1.48	15.90	17.66	28.26	29.67	9.0	16.8	1.9
1.30	1127.	3.05	1.53	1.45	14.14	17.28	27.65	31.20	8.2	18.1	2.0
1.40	984.	2.99	1.42	1.50	13.23	15.67	25.40	29.07	8.3	18.3	2.0
1.50	212.	2.33	1.54	1.51	17.41	17.33	27.73	28.65	10.0	16.5	1.9
1.60	787.	2.90	1.56	1.53	12.05	14.04	22.46	27.47	9.6	19.6	2.1
1.70	3568.	3.55	1.50	1.62	12.64	18.31	29.30	23.95	6.9	13.1	1.7
1.80	1638.	3.21	1.80	1.71	11.95	15.39	24.62	20.74	7.8	13.5	1.7
1.90	950.	2.98	1.83	1.77	12.07	14.42	23.07	18.87	8.4	13.1	1.7
2.00	1193.	3.08	1.67	1.70	14.99	18.46	29.54	21.07	8.1	11.4	1.6
2.10	1849.	3.27	1.61	1.59	15.93	26.12	41.79	25.29	7.6	9.7	1.5
2.20	1931.	3.29	1.49	1.56	22.76	30.01	48.01	26.34	7.6	8.8	1.4
2.30	1077.	3.03	1.59	1.56	24.78	30.10	48.16	26.26	8.2	8.7	1.4
2.40	951.	2.98	1.61	1.61	21.87	26.13	41.81	24.27	8.4	9.3	1.5
HANG SITE 11 DATE: 9/21/76 SAMPLE NO. 1											
0.10	126451.	5.10	1.23	1.23	8.37	28.55	45.67	43.80	2.9	15.3	1.8
0.20	38842.	4.59	1.58	1.39	7.01	16.53	26.44	33.97	4.2	20.6	2.2
0.30	49257.	4.69	1.38	1.47	7.89	19.83	31.73	30.33	4.0	15.3	1.8
0.40	40302.	4.61	1.45	1.41	6.23	14.81	23.70	33.24	4.2	22.4	2.3
0.50	89030.	4.95	1.40	1.50	6.47	19.49	31.19	28.93	3.3	14.8	1.8
0.60	86780.	4.94	1.65	1.40	6.38	19.03	30.45	33.69	3.3	17.7	2.0
0.70	107196.	5.03	1.15	1.48	10.42	33.47	53.55	29.95	3.1	8.9	1.5
0.80	36574.	4.56	1.63	1.46	5.25	12.19	19.50	30.97	4.3	25.4	2.4
0.90	52974.	4.72	1.58	1.53	5.17	13.27	21.23	27.51	3.9	20.7	2.2
1.00	7276.	3.86	1.38	1.48	6.93	11.34	18.15	29.83	5.1	26.3	2.5
1.10	3850.	3.59	1.48	1.43	10.59	15.55	24.87	32.18	4.8	20.7	2.2
1.20	2164.	3.34	1.43	1.37	12.29	16.49	26.38	35.07	7.5	21.3	2.2
1.30	880.	2.94	1.21	1.32	17.35	20.52	32.83	37.86	8.5	18.5	2.0
1.40	211.	2.32	1.32	1.41	19.08	18.99	30.38	33.24	10.0	17.5	2.0
1.50	128.	2.11	1.69	1.52	17.38	16.39	26.22	27.93	10.6	17.0	1.9
1.60	92.	1.96	1.55	1.57	16.36	14.91	23.65	26.15	11.0	17.5	2.0
1.70	73.	1.86	1.45	1.52	20.47	18.22	29.16	28.14	11.2	15.4	1.8
1.80	52.	1.72	1.55	1.58	16.14	13.91	22.26	25.60	11.6	18.4	2.0
1.90	44.	1.64	1.74	1.46	12.67	10.91	17.46	30.57	11.8	28.0	2.5
2.00	32.	1.51	1.11	1.36	21.95	18.09	28.94	35.72	12.1	19.7	2.1
2.10	37.	1.57	1.24	1.26	18.35	15.31	24.49	41.41	12.0	27.1	2.5
2.20	19.	1.27	1.44	1.38	24.62	19.32	30.91	34.50	12.7	17.9	2.0
2.30	55.	1.74	1.47	1.53	27.25	23.63	37.80	27.73	11.5	11.7	1.6
2.40	52.	1.72	1.67	1.48	27.50	23.70	37.92	29.88	11.6	12.6	1.7
2.50	7.	0.83	1.30	1.50	29.60	21.35	34.17	29.04	13.9	13.5	1.7
2.60	19.	1.27	1.52	1.43	31.08	24.38	39.01	32.06	12.7	13.2	1.7
2.70	12.	1.08	1.48	1.56	23.41	21.48	34.37	26.49	13.2	12.3	1.7
2.80	27.	1.43	1.67	1.58	29.28	23.73	37.97	25.39	12.3	10.7	1.6
2.90	10.	0.98	1.61	1.64	27.97	20.75	33.20	23.25	13.5	11.2	1.6
3.00	10.	0.98	1.64	1.65	26.18	19.42	31.07	22.83	13.5	11.8	1.5
3.10	16.	1.20	1.70	1.70	28.55	22.09	35.34	20.97	12.9	9.5	1.5

M DEPTH	RETENTION FORCE		VOLUME WEIGHT	AVERAGE VOLUME WEIGHT	SOIL MOISTURE	MOISTURE RETENTION CAPABILITY	ADSORPTION CAPACITY	VOID MOISTURE CAPACITY	SOIL MOISTURE	VOID MOISTURE CAPACITY	PERMEABILITY
M	G/SQCM	PF	G/CC	G/CC	%	%	%	%	MOLECULAR LAYERS OF WATER	MOLECULAR LAYERS OF WATER	CM/HR
HANG SITE 13 DATE: 9/21/76 SAMPLE NO. 1											
0.10	274448.	5.44	1.12	1.12	6.46	31.22	49.96	51.95	2.1	16.6	1.9
0.20	120857.	5.08	1.26	1.30	7.67	25.71	41.14	39.39	3.0	15.3	1.8
0.30	113700.	5.06	1.51	1.44	8.05	26.41	42.26	31.94	3.0	12.1	1.6
0.40	65692.	4.82	1.53	1.50	8.57	23.42	37.47	29.02	3.7	12.4	1.7
0.50	81142.	4.91	1.45	1.51	9.25	27.02	43.24	28.29	3.4	10.5	1.5
0.60	82097.	4.91	1.56	1.48	8.53	24.99	39.98	29.81	3.4	11.9	1.6
0.70	57799.	4.76	1.43	1.52	9.46	24.88	39.80	28.09	3.8	11.3	1.6
0.80	71231.	4.85	1.57	1.52	9.58	26.83	42.93	27.94	3.6	10.4	1.5
0.90	62131.	4.79	1.57	1.55	8.88	23.85	38.16	26.66	3.7	11.2	1.6
1.00	42238.	4.63	1.52	1.47	8.70	20.96	33.53	30.31	4.2	14.5	1.8
1.10	40353.	4.61	1.32	1.52	9.04	21.51	34.41	28.01	4.2	13.0	1.7
1.20	36578.	4.59	1.73	1.53	9.48	22.30	35.68	27.53	4.3	12.3	1.7
1.30	24873.	4.40	1.55	1.60	10.64	22.44	35.91	24.75	4.7	11.0	1.6
1.40	23164.	4.36	1.52	1.53	10.68	22.16	35.45	27.53	4.8	12.8	1.7
1.50	19030.	4.29	1.52	1.41	11.85	23.53	37.64	32.98	5.0	14.0	1.8
1.60	17161.	4.23	1.20	1.43	10.9	21.24	33.99	32.44	5.2	15.3	1.8
1.70	17847.	4.25	1.55	1.38	11.41	22.33	35.72	34.73	5.1	15.6	1.9
1.80	13717.	4.14	1.39	1.51	12.22	22.62	35.19	28.68	5.4	12.7	1.7
1.90	9791.	3.99	1.58	1.43	12.34	21.35	34.16	32.11	5.8	15.0	1.8
2.00	11447.	4.05	1.33	1.45	11.79	21.04	33.67	31.40	5.6	14.9	1.8
2.10	13192.	4.12	1.43	1.38	12.50	22.95	36.71	34.63	5.4	15.1	1.8
2.20	11068.	4.04	1.38	1.45	13.21	23.42	37.47	31.01	5.6	13.2	1.7
2.30	11042.	4.04	1.55	1.50	12.30	21.79	34.86	28.96	5.6	13.3	1.7
2.40	11657.	4.07	1.57	1.57	11.90	21.31	34.10	26.07	5.6	12.2	1.6
HANG SITE 14 DATE: 9/21/76 SAMPLE NO. 1											
0.10	57607.	4.76	0.89	0.89	6.11	16.05	25.68	74.81	3.8	46.6	3.7
0.20	30547.	4.48	1.45	1.34	8.21	18.19	29.10	36.99	4.5	20.3	2.1
0.30	26131.	4.42	1.68	1.61	9.15	19.53	31.26	24.33	4.7	12.4	1.7
0.40	22184.	4.35	1.71	1.60	9.13	16.70	26.72	24.94	4.9	14.9	1.8
0.50	14266.	4.15	1.40	1.62	8.78	16.38	26.21	23.89	5.4	14.6	1.8
0.60	6875.	3.84	1.76	1.62	10.16	16.46	26.34	24.17	6.2	14.7	1.8
0.70	1645.	3.22	1.68	1.75	13.60	17.52	28.03	19.46	7.8	11.1	1.6
0.80	1043.	3.02	1.80	1.73	18.24	22.06	35.29	20.21	8.3	9.2	1.5
0.90	875.	2.94	1.69	1.71	17.21	20.33	32.53	20.64	8.5	10.3	1.5
1.00	983.	2.99	1.63	1.61	16.42	19.70	31.52	24.28	8.3	12.3	1.7
1.10	1304.	3.12	1.51	1.63	21.17	26.40	42.24	23.61	8.0	8.9	1.5
1.20	1558.	3.19	1.75	1.66	18.83	24.08	38.52	22.66	7.8	9.4	1.5
1.30	817.	2.91	1.71	1.75	19.24	22.53	36.05	19.35	8.5	8.6	1.4
1.40	1572.	3.20	1.80	1.74	20.31	25.99	41.59	19.82	7.8	7.6	1.4
1.50	1316.	3.12	1.70	1.73	18.21	22.73	36.37	20.01	8.0	8.8	1.4
1.60	671.	2.83	1.69	1.87	18.26	20.85	33.36	15.69	8.8	7.5	1.4
1.70	565.	2.75	2.22	1.86	17.09	15.09	30.55	15.93	9.0	8.3	1.4
1.80	337.	2.53	1.68	1.97	15.83	16.62	26.59	13.01	9.5	7.8	1.4
1.90	216.	2.33	2.01	1.86	16.87	16.83	26.93	16.03	10.0	9.5	1.5
2.00	267.	2.43	1.89	1.94	16.05	17.02	27.23	13.72	9.8	8.1	1.4
2.10	1489.	3.17	1.93	1.85	19.34	24.57	39.31	16.43	7.9	6.7	1.3
2.20	1733.	3.24	1.72	1.92	20.52	26.63	42.61	14.26	7.7	5.8	1.2
2.30	1671.	3.22	2.12	1.79	18.44	23.61	38.09	18.25	7.7	7.7	1.4
2.40	1060.	3.03	1.52	1.52	17.66	21.41	34.25	28.08	8.3	13.1	1.7
HANG SITE 18 DATE: 9/21/76 SAMPLE NO. 1											
0.10	198432.	5.30	1.44	1.44	3.52	14.50	23.20	31.59	2.8	21.8	2.2
0.20	61506.	4.79	1.48	1.44	6.02	16.13	25.81	31.73	3.7	19.7	2.1
0.30	55749.	4.75	1.39	1.38	5.28	13.73	21.97	34.97	3.8	25.5	2.5
0.40	55432.	4.74	1.25	1.55	4.97	12.92	20.67	26.65	3.8	20.6	2.2
0.50	55128.	4.74	2.02	1.70	5.09	13.20	21.12	21.12	3.9	16.0	1.9
0.60	44068.	4.64	1.83	1.82	7.46	18.19	29.10	17.35	4.1	9.5	1.5
0.70	27235.	4.44	1.60	1.76	12.50	26.94	43.10	19.14	4.6	7.1	1.3
0.80	29456.	4.47	1.84	1.74	9.98	21.92	35.07	19.62	4.6	9.0	1.5
0.90	20981.	4.32	1.79	1.84	9.30	16.88	30.20	16.75	4.9	8.9	1.4
1.00	12962.	4.11	1.87	1.79	8.74	15.99	25.59	18.10	5.5	11.3	1.6
1.10	6660.	3.82	1.71	1.78	10.63	17.13	27.41	18.51	6.2	10.8	1.6
1.20	2676.	3.43	1.75	1.72	11.10	15.37	24.59	20.31	7.2	13.2	1.7
1.30	2804.	3.45	1.71	1.74	4.56	6.36	10.18	19.58	7.2	30.8	2.8
1.40	3078.	3.49	1.78	1.73	6.38	9.03	14.45	20.06	7.1	22.2	2.3
1.50	2113.	3.32	1.70	1.68	6.37	8.51	13.61	21.83	7.5	25.7	2.5
1.60	2094.	3.32	1.55	1.55	6.89	9.19	14.71	26.61	7.5	28.9	2.7

MANG SITE 15 DATE: 9/21/76 SAMPLE NO. 1

DEPTH (M)	RETENTION FORCE G/SQCM	PF	VOLUME WEIGHT G/CC	AVERAGE VOLUME WEIGHT G/CC	SOIL MOISTURE %	MOISTURE RETENTION CAPABILITY %	ADSORPTION CAPACITY %	VOID MOISTURE CAPACITY %	SOIL MOISTURE MOLECULAR LAYERS OF WATER	VOID MOISTURE CAPACITY MOLECULAR LAYERS OF WATER	PERMEABILITY CM/HR
0.10	193528.	5.29	1.12	1.12	3.75	15.29	24.46	51.79	2.5	33.9	3.0
0.20	47946.	4.68	1.44	1.33	11.06	27.59	44.14	37.20	4.0	13.5	1.7
0.30	50940.	4.71	1.45	1.44	10.54	26.74	42.79	31.55	3.9	11.8	1.6
0.40	40382.	4.61	1.44	1.49	9.54	22.70	36.32	29.42	4.2	13.0	1.7
0.50	45496.	4.66	1.57	1.57	8.28	20.35	32.56	26.15	4.1	12.8	1.7
0.60	37596.	4.58	1.68	1.62	8.05	18.80	30.09	24.01	4.3	12.8	1.7
0.70	33423.	4.52	1.61	1.60	8.02	18.18	29.09	24.70	4.4	13.6	1.7
0.80	30432.	4.48	1.52	1.53	8.83	19.55	31.28	27.45	4.5	14.0	1.8
0.90	21552.	4.33	1.48	1.50	10.19	20.80	33.28	29.04	4.9	14.0	1.8
1.00	6317.	3.80	1.50	1.51	12.01	19.16	30.66	28.30	6.3	14.8	1.8
1.10	2572.	3.41	1.57	1.52	12.22	16.82	26.91	28.03	7.3	16.7	1.9
1.20	1376.	3.14	1.49	1.54	14.62	18.37	29.39	27.16	8.0	14.8	1.8
1.30	894.	2.95	1.56	1.55	14.16	16.73	26.85	26.44	8.4	15.9	1.9
1.40	1063.	3.03	1.61	1.64	10.74	13.02	20.83	23.37	8.2	18.0	2.0
1.50	1533.	3.19	1.74	1.60	9.64	12.55	20.09	24.60	7.8	19.6	2.1
1.60	957.	2.98	1.46	1.64	8.82	10.54	16.87	23.34	8.4	22.1	2.3
1.70	800.	2.90	1.71	1.59	10.58	12.35	19.76	25.05	8.6	20.3	2.1
1.80	576.	2.75	1.61	1.66	11.62	13.24	21.18	22.46	8.9	17.1	1.9
1.90	682.	2.83	1.65	1.63	13.64	15.60	24.97	23.69	8.7	15.2	1.8
2.00	623.	2.79	1.62	1.67	8.29	9.38	15.00	22.17	8.8	23.6	2.3
2.10	250.	2.40	1.73	1.67	10.95	11.11	17.78	22.17	9.9	19.9	2.1
2.20	217.	2.34	1.65	1.64	9.96	9.94	15.91	23.10	10.0	23.2	2.3
2.30	208.	2.32	1.55	1.66	16.73	16.63	26.61	22.66	10.1	13.6	1.7
2.40	619.	2.79	1.77	1.77	17.50	19.78	31.64	18.76	8.8	9.5	1.5

MANG SITE 16 DATE: 9/21/76 SAMPLE NO. 1

DEPTH (M)	RETENTION FORCE G/SQCM	PF	VOLUME WEIGHT G/CC	AVERAGE VOLUME WEIGHT G/CC	SOIL MOISTURE %	MOISTURE RETENTION CAPABILITY %	ADSORPTION CAPACITY %	VOID MOISTURE CAPACITY %	SOIL MOISTURE MOLECULAR LAYERS OF WATER	VOID MOISTURE CAPACITY MOLECULAR LAYERS OF WATER	PERMEABILITY CM/HR
0.10	280330.	5.45	0.99	0.99	6.60	32.27	51.63	63.61	2.0	19.7	2.1
0.20	136988.	5.14	1.52	1.35	7.93	27.90	44.64	36.47	2.8	13.1	1.7
0.30	106110.	5.03	1.53	1.50	8.76	28.02	44.83	28.92	3.1	10.3	1.5
0.40	71587.	4.85	1.44	1.58	7.99	22.42	35.68	25.62	3.6	11.4	1.6
0.50	78324.	4.89	1.76	1.57	6.79	19.59	31.35	26.08	3.5	13.3	1.7
0.60	83082.	4.92	1.50	1.64	7.61	22.40	35.83	23.20	3.4	10.4	1.5
0.70	68531.	4.84	1.67	1.52	7.43	20.56	32.90	28.15	3.6	13.7	1.7
0.80	77133.	4.89	1.39	1.50	9.98	28.67	45.87	29.04	3.5	10.1	1.5
0.90	60422.	4.91	1.44	1.43	9.07	26.41	42.25	32.06	3.4	12.1	1.6
1.00	42346.	4.63	1.47	1.42	7.70	18.57	29.71	32.55	4.1	17.5	2.0
1.10	41766.	4.62	1.36	1.43	8.89	21.36	34.18	32.02	4.2	15.0	1.8
1.20	36680.	4.56	1.47	1.45	9.37	21.76	34.81	31.34	4.3	14.4	1.8
1.30	29264.	4.47	1.52	1.52	10.52	23.07	36.91	27.89	4.6	12.1	1.6
1.40	27346.	4.44	1.59	1.57	10.72	23.13	37.00	26.15	4.6	11.3	1.6
1.50	25207.	4.40	1.59	1.58	11.52	24.39	39.02	25.38	4.7	10.4	1.5
1.60	17266.	4.24	1.57	1.62	11.80	22.93	36.69	24.01	5.1	10.5	1.5
1.70	20732.	4.32	1.69	1.70	11.94	24.16	38.66	21.01	4.9	8.7	1.4
1.80	19309.	4.29	1.64	1.66	12.01	23.91	38.26	21.76	5.0	9.1	1.5
1.90	12372.	4.09	1.51	1.65	13.22	23.95	38.33	22.77	5.5	9.5	1.5
2.00	12925.	4.11	1.61	1.53	12.87	23.54	37.66	27.74	5.5	11.8	1.6
2.10	9290.	3.97	1.46	1.56	12.81	21.95	35.12	26.36	5.8	12.0	1.6
2.20	8073.	3.91	1.61	1.51	13.60	22.69	36.31	28.28	6.0	12.5	1.7
2.30	6560.	3.82	1.47	1.59	13.23	21.26	34.01	25.17	6.2	11.8	1.6
2.40	5351.	3.73	1.69	1.69	10.75	16.67	26.67	21.48	6.4	12.9	1.7

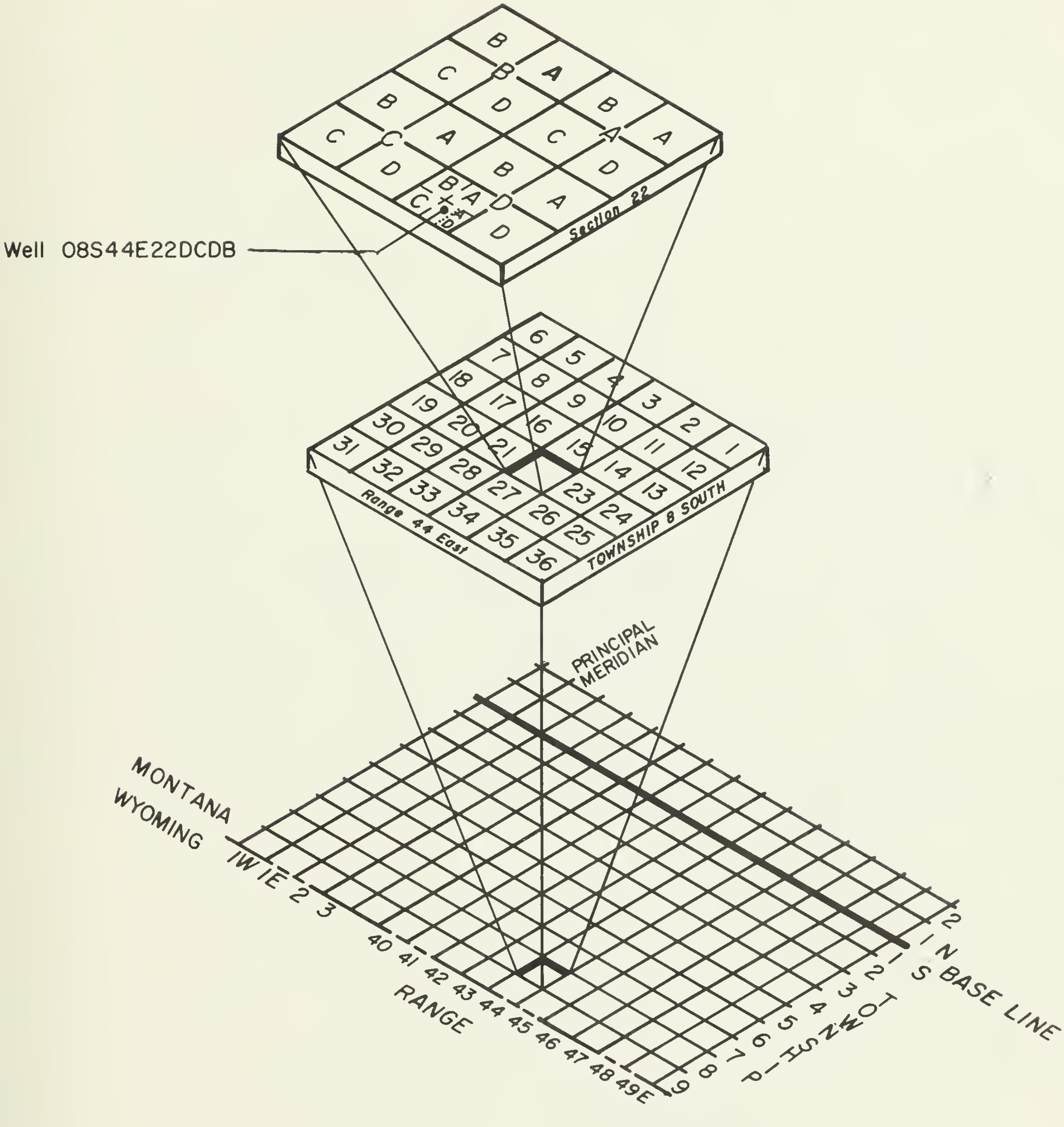
MANG SITE 17 DATE: 9/21/76 SAMPLE NO. 1

DEPTH (M)	RETENTION FORCE G/SQCM	PF	VOLUME WEIGHT G/CC	AVERAGE VOLUME WEIGHT G/CC	SOIL MOISTURE %	MOISTURE RETENTION CAPABILITY %	ADSORPTION CAPACITY %	VOID MOISTURE CAPACITY %	SOIL MOISTURE MOLECULAR LAYERS OF WATER	VOID MOISTURE CAPACITY MOLECULAR LAYERS OF WATER	PERMEABILITY CM/HR
0.10	183659.	5.26	0.96	0.96	4.41	17.51	28.02	66.10	2.5	37.7	3.2
0.20	78523.	4.89	1.66	1.42	7.34	21.21	33.93	32.68	3.5	15.4	1.8
0.30	55193.	4.74	1.64	1.45	7.32	19.00	30.40	31.37	3.9	16.5	1.9
0.40	33665.	4.53	1.04	1.29	8.89	20.19	32.30	40.00	4.4	19.8	2.1
0.50	35615.	4.55	1.18	1.15	8.33	19.19	30.70	49.57	4.3	25.8	2.5
0.60	30866.	4.49	1.21	1.24	10.26	22.85	36.55	43.19	4.5	18.9	2.1
0.70	20851.	4.32	1.31	1.35	9.61	19.47	31.15	36.37	4.9	18.7	2.0
0.80	7155.	3.85	1.52	1.53	11.20	18.28	29.25	27.55	6.1	15.1	1.8
0.90	2674.	3.43	1.76	1.69	13.06	18.08	28.93	21.46	7.2	11.9	1.6
1.00	1600.	3.20	1.79	1.79	14.30	18.35	29.37	18.15	7.8	9.9	1.5
1.10	1830.	3.26	1.82	1.82	13.88	18.15	29.05	17.08	7.6	9.4	1.5
1.20	2675.	3.43	1.87	1.92	15.69	22.01	35.21	14.48	7.2	6.6	1.3
1.30	2364.	3.37	2.06	2.06	16.99	23.09	36.94	10.83	7.4	4.7	1.2

APPENDIX I

System for Describing Geographic Locations

Wells and sites described in this report are specified by location according to the General Land Office system of land subdivision. The first three characters of the location code specify the Township South, S, of the Montana base line; the next three, the Range East, E, of the principal meridian Montana. The next two characters specify the section number within the township. The final four letters specify the location within the quarter section (160-acre tract), the quarter-quarter section (40-acre tract), the quarter-quarter-quarter section (10-acre tract), and the quarter-quarter-quarter-quarter section (2 1/2-acre tract). Subdivisions of a section are designated A, B, C, and D in a counterclockwise direction, beginning in the northeast quadrant. For example, a well numbered 08S44E22DCDB would be located in the NW 1/4 of the SE 1/4 of the SW 1/4 of the SE 1/4 of Section 22, Township 8 South, Range 44 East. If more than one well is located within the same 2 1/2-acre tract, consecutive digits are added to the end of the location number.



Appendix I. System for Describing Geographic Locations.

APPENDIX J

Lithologic Logs of Drill Holes

[Land-surface altitudes are referenced to mean sea level datum. Depth of drill hole and depth to water are reported in feet below land surface. Depth of drill hole is reported to the nearest foot where the samples were cuttings and to the nearest 0.1 foot where the samples were cores.]

Test well: HWC-02
Location: 09S43E03CDDA1
Date drilled: 5-13-74

Land-surface altitude: 3,542 ft
Total depth: 296 ft
Depth to water: 63 ft
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 273 to 290 feet; formation packer at 270 feet.

Depth	Lithologic description
0-10	Silt and clay, yellow; some small pebbles
10-11	Silt and sand, fine, light-brown
11-16	Siltstone, moderately resistant
16-22	Silt and clay, red, light-brown
22-32	Sand and silt, very fine, poorly consolidated, buff
32-37	Sand and silt, very fine with considerable clay, brown
37-46	Clay, sandy and silty, grayish-brown
46-48	Siltstone, resistant
48-76	Clay, slightly silty, heavy, grayish-brown; thin sandstone and siltstone interbeds, some coal
76-77	Coal
77-88	Clay, silty with coal streaks, grayish-brown
88-91	Shale, carbonaceous
91-92	Shale, clayey, brown
92-96	Coal
96-97	Clay, plastic, gray
97-104	Coal
104-107	Clay, slightly silty, plastic, gray
107-112	Siltstone, moderately resistant, light-gray
112-113	Shale, slightly silty, gray
113-114	Coal
114-117	Shale, slightly silty, gray
117-118	Siltstone, resistant, dark-gray
118-119	Siltstone, very clayey, soft, brown
119-120	Siltstone, resistant
120-121	Shale, dark-grayish-brown
121-122	Shale, carbonaceous
122-124	Coal
124-128	Shale, very clayey, gray, with some siltstone interbeds
128-138	Siltstone, clayey, soft, gray
138-139	Coal
139-148	Shale, slightly silty, gray; becomes siltier with depth, some carbonaceous partings
148-153	Siltstone, very clayey, brown-buff
153-169	Shale, silty, dark-gray; some coal (possible caving)
169-171	Siltstone, soft, white-cream

Test well HWC-02--continued

171-174	Siltstone, soft, yellowish-brown
174-179	Shale, very silty, soft, dark-gray
179-184	Coal
184-195	Shale, very clayey, some silt, light-gray, with carbonaceous partings abundant to 187 ft
195-196	Shale, carbonaceous, some coal
196-199	Coal
199-209	Shale, very silty, gray
209-210	Siltstone, resistant
210-211	Sandstone, medium-grained, yellow
211-212	Siltstone, resistant, dark-gray
212-217	Shale, silty, gray
217-218	Siltstone, moderately resistant, gray
218-227	Siltstone, less resistant, gray
227-230	Siltstone, moderately resistant, slightly shaley, gray
230-253	Shale, silty, clayey with some resistant siltstone interbeds, fairly soft, gray
253-255	Shale, silty, clayey, soft, tan
255-257	Clay, plastic, gray
257-268	Clay, silty, less cohesive, gray
268-270	Clay, very silty, poorly consolidated, buff
270-272	Siltstone, moderately resistant
272-291	Coal (Canyon)
291-296	Siltstone, soft, gray

Test well: HWC-03
Location: 09S43E03CDDA2
Date drilled: 5-14-74

Land-surface altitude: 3,539 ft
Total depth: 108 ft
Depth to water: 36 ft
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 91 to 104 feet; formation packer at 89 feet.

Depth	Lithologic description
0-10	Silt and clay, light-yellow-brown
10-14	Siltstone, silt, and sand, fine-grained, grayish-brown
14-22	As above, slightly clayey
22-27	Silt and sand, very fine-grained, unconsolidated, light-brown
27-33	Silt and clay, medium-dark-brown
33-44	Silt and clay, gray-brown
44-45	Siltstone, resistant
45-79	Silt and clay, soft, dark-gray
79-80	Coal and shale, carbonaceous
80-87	Shale, silty, dark-gray
87-91	Shale, carbonaceous
91-95	Coal
95-96	Shale, very clayey, light-gray
96-105	Coal
105-108	Shale, very clayey, gray

Test well: HWC-15
Location: 09S43E22ACCA
Date drilled: 8-4-76

Land-surface altitude: 3,595 ft
Total depth: 129 ft
Depth to water: 31 ft
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 100 to 126 feet, formation packer at 97 feet.

Depth	Lithologic description
0-2	Soil, clayey, brown
2-4	Clay, brown
4-7	Clay, light-gray
7-9	Siltstone, very hard, gray
9-12	Silt and clay, olive-brown
12-15	Sand, silty, brown
15-22	Clay, dark-brown
22-39	Clay and silt, silty, gray with carbonaceous material
39-40	Siltstone, hard
40-43	Clay, gray
43-51	Clay, silty, gray with carbonaceous partings
51-54	Clay, carbonaceous
54-61	Sandstone, very fine grained, loosely cemented, gray
61-73	Silt, gray
73-100	Clay and some silt, very carbonaceous
100-126	Coal (Anderson)
126-129	Clay, brownish-gray

Test well: HWC-16
Location: 09S43E27DABB
Date drilled: 8-9-76

Land-surface altitude: 3,645 ft
Total depth: 375 ft
Depth to water: 59 ft
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 343 to 370 feet; formation packer at 337 feet.

Depth	Lithologic description
0-2	Soil, clayey, brown
2-21	Sandstone, fine-grained, silty, very hard, highly calcareous, light-gray
21-25	Silt, light-brown
25-38	Clay, dark-gray
38-47	Clay, silty, dark-gray
47-58	Shale with gypsum, dark-gray
58-64	Sand, silty, dark-gray
64-66	Coal
66-74	Shale, carbonaceous, gray
74-82	Sand, silty, gray
82-153	Shale, carbonaceous, interbedded with sand, dark-gray
153-154	Coal
154-156	Clay, oxidized (carbonaceous shale)
156-159	Coal
159-176	Shale, carbonaceous, brown
176-178	Siltstone, hard, light-gray
178-206	Shale, silty, carbonaceous with few sandstone lenses, gray
206-209	Coal
209-211	Shale
211-214	Coal
214-220	Shale, silty
220-232	Siltstone, with alternating hard ledges of limy siltstone, gray
232-251	Claystone, silty, gray
251-254	Sandstone, silty, well-cemented, hard, gray
254-260	Sandstone, poorly cemented
260-265	Shale, with calcite crystals, dark-gray
265-270	Siltstone
270-282	Shale, dark-gray
282-283	Coal
283-343	Claystone, highly carbonaceous, gray
343-370	Coal (Anderson)
370-375	Shale, carbonaceous

Test well: HWC-17
Location: 09S43E13BDBB
Date drilled: 8-10-76

Land-surface altitude: 3,604 ft
Total depth: 82 ft
Depth to water: 51 ft
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 51 to 77 feet; formation packer at 46 feet.

Depth	Lithologic description
0-14	Soil, silty, and silt, tan
14-21	Silt, grayish-tan
21-28	Sand, clayey, gray
28-33	Sand, fine, brown
33-45	Shale, dark-gray, with some carbonaceous material and gypsum
45-53	Shale, very carbonaceous, weathered; coal, 51-53 feet
53-77	Coal (Anderson)
77-82	Clay, gray

Test well: HWC-18
Location: 09S44E08BDDC
Date drilled: 8-11-76

Land-surface altitude: 3,670 ft
Total depth: 243 ft
Depth to water: 22 ft
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 216 to 239 feet; formation packer at 211 feet.

Depth	Lithologic description
0-2	Silt, brown
2-8	Colluvium
8-14	Clay, reddish-brown
14-27	Sandstone, tan
27-36	Clay, silty, gray
36-44	Shale, medium-gray
44-48	Clay, sandy gray
48-56	Clay, gray, with carbonaceous material
52-57	Coal
57-89	Shale, gray
89-90	Coal
90-110	Shale and silt, interbedded, gray
110-121	Sandstone and silt, fine-grained
121-123	Siltstone, hard, gray
123-131	Sandstone, fine-grained, well-cemented
131-166	Shale, gray
166-167	Coal
167-172	Shale, carbonaceous
172-173	Coal
173-206	Shale, carbonaceous, gray
206-239	Coal (Anderson)
239-243	Shale, carbonaceous, brownish-gray

Test well: HWC-19
Location: 09S44E16ACCB
Date drilled: 8-13-76

Land-surface altitude: 3,800 ft
Total depth: 183 ft
Depth to water: 100 ft
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 148 to 178 feet; formation packer at 143 feet.

Depth	Lithologic description
0-1	Colluvium
1-9	Sandstone, very fine grained, tan, with interbedded brown clay
9-18	Silt, brown
18-22	Clay, grayish-brown
22-26	Shale, bluish-gray
26-27	Coal
27-30	Shale, bluish-gray
30-34	Shale, "smutty," gray, with carbonaceous streaks
34-53	Shale, silty, bluish-gray
53-56	Shale, silty, with carbonaceous material
56-63	Siltstone, hard, gray
63-74	Sand, very fine, clayey
74-82	Sand, very fine, and silt, gray
82-93	Shale, very carbonaceous
93-120	Silt, gray
120-128	Sandstone, very fine grained, gray
128-132	Shale, gray
132-148	Shale, carbonaceous
148-178	Coal (Anderson)
178-183	Siltstone, gray

Test well: HWC-20
Location: 09S44E07ADCD
Date drilled: 8-20-76

Land-surface altitude: 3,676 ft
Total depth: 132 ft
Depth to water: 58 ft
Sample source: core

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 93 to 122 feet; formation packer at 89 feet.

Depth	Lithologic description
0-4	Soil, silty, and silt, tan
4-10	Sand, clayey, brown
10-20	Sandstone, soft, brownish-gray
20-21.5	Limestone, dirty, gray
21.5-24	Claystone, tan
24-26	No recovery
26-30	Clay, silty, steel-gray
30-33	Clay, steel-gray, with very thin sandstone streaks
33-34	No recovery
34-36.5	Clay, steel-gray, with silt in thin laminae
36.5-45.5	Sandstone, very fine grained, gray, with 1 foot oxidized yellowish-red zone at 38 ft
45.5-50.5	Clay, gray, carbonaceous from 48 ft through 50 ft
50.5-51	Coal
51-58.5	Sandstone, fine-grained, gray, with carbonaceous material
58.5-66	Shale, very carbonaceous, with few coal partings and numerous fossils, gastropods, cephalopods, and plant material
66-66.3	Coal
66.3-67	Clay, carbonaceous, gray
67-71	Clay, silty, gray
71-81	Shale, carbonaceous, black
81-93	Shale, silty, gray
93-122	Coal (Anderson), parting at 119.5-120 ft
122-122.5	Clay, carbonaceous
122.5-127	Sandstone, fine-grained, with carbonaceous laminae, gray
127-128	Clay, carbonaceous
128-129	Sandstone, fine grained, gray
129-132	Clay, carbonaceous

Test well: HWC-21
Location: 09S43E02BBB1
Date drilled: 8-27-76

Land-surface altitude: 3,665 ft
Total depth: 217 ft
Depth to water: 168 ft
Sample source: core

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 200 to 211 feet; formation packer at 196 feet.

Depth	Lithologic description
0-7	Sandstone, very fine to fine-grained, grayish-tan
7-14	Sandstone, very fine grained, silty, gray
14-17	Sandstone (as above), oxidized, reddish-brown
17-20.5	Sandstone, very fine grained, gray
20.5-21	Coal
21-23	Claystone, with some carbonaceous material, dark-gray
24-32	Shale, silty, carbonaceous, with numerous plant impressions, with depth goes to siltstone and back to shale
32-33	Sandstone, very fine grained, gray
33-42	Siltstone, gray
42-46	Claystone and shale, gray
46-58	Clay, carbonaceous, brown, with coal streaks at 46.5 to 48 ft, 51.5 to 52 ft, 55.5 to 56 ft
58-61	Sandstone, very fine grained, gray
61-63	Sandstone, becoming clayey at 62 ft; becomes shale for 0.5 ft, then back to clayey sandstone
63-91	Sandstone, fine grained, poorly cemented; better cementation below 78 ft
91-94	Limestone, very hard, gray
94-105	Sandstone, very fine grained, with occasional carbonaceous material, gray
105-113	Shale, carbonaceous
113-143	Coal (Anderson)
143-147	Shale, carbonaceous, brown
147-162	Sandstone, very fine grained, well cemeted between 159 and 162 ft, gray
162-167	Siltstone, gray
167-168	Claystone, hard, brown
168-200	Clay, silty, grayish-brown; thin coal near 173 ft
200-211	Coal (Dietz)
211-213	Clay, carbonaceous, brown
213-217	Shale, light-gray

Test well: HWC-22
Location: 09S43E02BBBB2
Date drilled: 8-27-76

Land-surface elevation: 3,665 ft
Total depth: 145 ft
Depth to water: 127 ft
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 113 to 143 feet; formation packer at 109 feet.

Depth	Lithologic description
0-7	Sandstone, very fine to fine-grained, grayish-tan
7-14	Sandstone, very fine grained, silty, gray
14-17	Sandstone, as above, oxidized, reddish-brown
17-20	Sandstone, very fine grained, gray
20-21	Coal
21-23	Claystone, dark-gray, with some carbonaceous material
23-24	Claystone, buff; clay, silty, gray; and shale, carbonaceous
24-32	Shale, silty, carbonaceous, with numerous plant impressions
32-33	Sandstone, very fine grained, gray
33-42	Siltstone, gray
42-46	Claystone and shale, gray
46-58	Clay, carbonaceous, brown, with coal streaks
58-61	Sandstone, very fine grained, gray
61-63	Sandstone, becoming clayey at 62 ft; becomes shale for 0.5 ft, then back to clayey sandstone
63-91	Sandstone, fine grained, very poorly cemented, gray with coal streaks at 85 to 86 ft and 87 to 88 ft
91-94	Limestone, very hard, gray
94-105	Sandstone, very fine grained, gray, with occasional carbonaceous material
105-113	Shale, very carbonaceous
113-143	Coal (Anderson)
143-145	Shale, carbonaceous, brown

Test well: HWC-23
Location: 09S44E06BBBB1
Date drilled: 9-4-76

Land-surface altitude: 3,720 ft
Total depth: 172 ft
Depth to water: 139 ft
Sample source: core

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 138 to 167 feet; formation packer at 135 feet.

Depth	Lithologic description
0-8	Siltstone, some clayey silt, limy?
8-14	Claystone, reddish-brown, no recovery at 14 to 16 ft
16-26	Claystone, gray, with intermittent oxidized streaks
26-30	No recovery
30-33	Coal beds and clay, thin, carbonaceous, brown
33-45	Clay and silt, gray; mostly silt to about 40 ft
45-45.5	Coal
45.5-52	Clay and silt, gray, some oxidation in interval
52-57.2	Sandstone, fine-grained, buff
57.2-62	Sandstone, well-cemented, gray
62-65	Sandstone grading into carbonaceous silt
65-79	Claystone, carbonaceous, silty, gray
79-79.5	Coal, very thin stringer; shale, carbonaceous
79.5-87	Shale, gray
87-96	Sandstone, very fine grained, gray, with very loose coal stringers
96-110	Silt, clayey, gray, with carbonaceous material
110-138	Shale, very carbonaceous, black; silt, gray at 118 to 119 ft
138-167	Coal (Anderson)
167-168	Clay and shale, carbonaceous, brown
168-171	Sandstone, fine-grained, gray
171-172	Shale and sandstone, alternating, gray

Test well: HWC-24
Location: 09S44E06BBBB2
Date drilled: 9-14-76

Land-surface altitude: 3,720 ft
Total depth: 201 ft
Depth to water: dry
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 187 to 196 feet; formation packer at 184 feet.

Depth	Lithologic description
0-2	Soil, clayey, brown
2-4	Soil, clayey, buff
4-15	Claystone, gray
15-22	Silt and clay, gray
22-32	Sandstone, well-cemented, gray
32-35	Sandstone, clayey
35-49	Claystone, carbonaceous, gray
49-57	Shale, gray
57-66	Sandstone, poorly consolidated, gray
66-80	Silt, clayey, gray
80-108	Shale, carbonaceous
108-137	Coal (Anderson)
137-140	Clay, gray
140-141	Siltstone, hard, gray
141-148	Shale, carbonaceous, gray
148-164	Sand, clayey, gray
164-166	Sand, becoming claystone
166-169	Sand, gray
169-187	Shale, carbonaceous, gray; numerous thin carbonaceous partings, less carbonaceous between 178 and 185 ft; very carbonaceous at 185 to 187 ft
187-196	Coal (Dietz)
196-201	Clay, silty, gray

Test well: HWC-25
Location: 09S44E08BBAB1
Date drilled: 9-23-76

Land-surface altitude: 3,675 ft
Total depth: 180 ft
Depth to water: 98 ft
Sample source: core

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 165 to 177 feet; formation packer at 160 feet.

Depth	Lithologic description
0-3	Soil, silty and clayey, brown
3-10	Claystone, yellowish-brown
10-11.5	Claystone, gray, with carbonaceous laminae
11.5-12.5	Sandstone, fine-grained, tan
12.5-13.5	Limestone, hard, gray, and sandstone, weakly cemented, gray
13.5-14.5	Claystone, brown
14.5-15.5	Limestone
15.5-26.5	Sandstone, very fine to fine-grained, weakly cemented, gray, oxidized intermittently, carbonaceous at 20 to 23 ft
26.5-30	Silt, brown; sand, very fine grained, grading to clay near 30 ft with some carbonaceous material
30-34	Clay, steel-gray, with carbonaceous material
34-35	Claystone, very carbonaceous
35-42	Claystone, gray, with some carbonaceous material, silty from 35 to 37 ft
42-44.5	Claystone, very carbonaceous, with coal stringer
44.5-50	Sandstone, very fine to fine-grained, poorly cemented, gray, much carbonaceous material
50-53	No recovery
53-54	Shale, gray
54-62	Shale, carbonaceous, very carbonaceous from 56 to 62 ft
62-62.5	Limestone, gray
62.5-64	Siltstone, gray
64-73	Shale, carbonaceous
73-106	Coal (Anderson)
106-108	Clay, silty, gray
108-113	Sandstone, very fine grained, gray
113-115	Clay, carbonaceous, gray
115-115.5	Coal
115.5-117	Shale, carbonaceous
117-119	Siltstone, very hard, gray
119-122	No core retrieved
122-125	Claystone, silty, gray
125-126	Siltstone, gray
126-129	Claystone, gray, with hard lenses
129-130	Sandstone, very fine grained, gray
130-131	Claystone, gray
131-136	Sandstone, fine-grained, gray, with clay lenses

Test well HWC-25--continued

136-137	Sandstone, medium-grained, gray, with clay lenses
137-144	Clay, greasy, medium-dark-gray
144-145	Siltstone, very hard, light-gray
145-154	Clay, carbonaceous, medium-dark-gray to black
154-164	Clay, carbonaceous, black
164-165	Clay, as above, with coal stringers
165-177	Coal (Dietz)
177-179	Clay, silty, white to light-gray
179-180	Sandstone, very fine grained, friable, light-gray

Test well: HWC-26
Location: 09S44E08BBAB2
Date drilled: 9-28-76

Land-surface altitude: 3,675 ft
Total depth: 110 ft
Depth to water: 56 ft
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 73 to 105 feet; formation packer at 71 feet.

Depth	Lithologic description
0-3	Soil, silty, brown
3-10	Claystone, yellowish-brown
10-12	Claystone, gray, with carbonaceous laminae
12-14	Sandstone, fine-grained, tan, and limestone
14-16	Claystone, brown, and limestone
16-26	Sandstone, very fine to fine-grained, gray
26-30	Silt and sand, brown, grading to clay near 30 ft
30-34	Clay, gray, with carbonaceous material
34-35	Claystone, very carbonaceous
35-44	Claystone, carbonaceous
44-50	Sandstone, very fine to fine-grained, gray
50-53	No recovery
53-54	Shale, gray
54-62	Shale, carbonaceous
62-64	Limestone, gray; siltstone, gray
64-73	Shale, carbonaceous
73-106	Coal (Anderson)
106-108	Clay, silty, gray
108-110	Sandstone, very fine grained, gray

Test well: HWC-27
Location: 09S43E14DBBB
Date drilled: 10-7-76

Land-surface altitude: 3,710 ft
Total depth: 264 ft
Depth to water: 135 ft (2/15/77)
Sample source: core

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 231 to 259 feet; formation packer at 227 feet.

Depth	Lithologic description
0-1.5	Soil, silty, gray
1.5-4	Clay, brown
4-12	Sandstone, very fine grained, tan, becomes rust-brown; silt from 8 to 10 ft
12-20	Silt, clayey, tan; contains some carbonaceous material, grades to very carbonaceous shale from 18 to 20 ft
20-23	Shale, carbonaceous, with plant material
23-27	Coal
27-31	Shale, carbonaceous
31-33.5	Sandstone, fine-grained, soft, gray
33.5-39	Shale, carbonaceous; shale, gray; and sandstone, very fine grained.
39-41	Shale, carbonaceous
41.5-43.5	Sandstone, fine-grained, gray
43.5-48	Sandstone, fine-grained; siltstone and claystone
48-50.5	Claystone, slightly carbonaceous
50.5-57.5	Sandstone, very fine grained, gray
57.5-60.5	Shale, very carbonaceous, brown
60.5-63	Siltstone, gray
63-69	Shale, very carbonaceous, black
69-71	Coal
71-83	Sandstone, very fine grained, gray
83-88	Sandstone, very fine grained, clayey, gray
88-93	Sandstone, with less clay
93-101	Claystone, silty, gray, carbonaceous from 97 ft
101-105	Coal
105-108	Siltstone, gray
108-111	Claystone, gray
111.3-111.8	Coal
111.8-113	Claystone, silty, gray
113-117	Siltstone, gray
117-119	Claystone, gray, with some carbonaceous material
119-131	Siltstone, gray, with numerous carbonaceous laminae
131-133	Sandstone, very fine to fine-grained, clayey, gray
133-136	Claystone, gray, gets more carbonaceous with depth
136-136.5	Coal
136.5-139	Siltstone, gray
139-141	Claystone, gray

Test well HWC-27 -- continued

141-145	Siltstone, gray, very hard about 144 ft
145-148	Shale, gray
148-155	Siltstone, gray
155-157	Siltstone, very hard, gray; no log from 157 to 160 ft
160-163	Claystone, gray
163-165	Shale, carbonaceous, and very thin coal
165-170	Sandstone, very fine to fine-grained, gray with carbonaceous laminae and some clay layers
170-183	Sand, with more carbonaceous material; thin coal at 173 ft
183-191	Sand, grades into gray siltstone, fairly hard at 190 to 191 ft
191-192	Sandstone, very fine grained, gray
192-195	Sandstone, grading to carbonaceous shale
195-200	Siltstone, very hard, gray
200-209	Sandstone, very fine grained, clayey, gray, with some carbonaceous material
209-228	Shale, carbonaceous, brown
228-230	Shale, carbonaceous, black, almost coal
230-231	Shale, carbonaceous, brown
231-259	Coal (Anderson)
259-261	Claystone, slightly carbonaceous, brown
261-264	Claystone, gray

Test well: HWC-28
Location: 08S44E32DDAB
Date drilled: 5-10-77

Land-surface altitude: 3,738 ft
Total depth: 183 ft
Depth to water: 106 ft (5-12-77)
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 147 to 178 feet; formation packer at 144 feet.

Depth	Lithologic description
0-5	Soil, clayey, brown
5-9	Shale, carbonaceous, with coal
9-19	Claystone, carbonaceous, gray
19-23	Claystone, silty, tan
23-24	Siltstone, hard gray
24-39	Claystone, tan, to shale, gray at 24 to 30 ft
39-44	Coal
44-58	Shale, bluish-gray
58-63	Sandstone, very fine to fine-grained, gray
63-104	Shale, silty, carbonaceous, gray; very carbonaceous from about 95 ft
104-105	Siltstone, hard
105-147	Shale, very carbonaceous
147-178	Coal, parting near 175 ft
178-183	Clay, gray

Test well: HWC-29
Location: 09S44E07BBCC1
Date drilled: 5-13-77

Land-surface altitude: 3,620 ft
Total depth: 94 ft
Depth to water: 47 ft (6-07-77)
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 57 to 89 feet; formation packer at 54 feet.

Depth	Lithologic description
0-1	Soil, clayey, tan
1-9	Sandstone, fine-grained, tan
9-12	Claystone, gray
12-16	Claystone, thin layers, and very fine grained sandstone
16-19	Claystone, brown
19-23	Siltstone, clayey, brown
23-31	Shale, carbonaceous, gray, with gypsum
31-34	Shale, brown
34-57	Shale, carbonaceous; very carbonaceous at 50 to 57 ft
57-89	Coal
89-94	Clay and shale, gray

Test well: HWC-29A
Location: 09S44E07BBCC2
Date drilled: 5-13-77

Land-surface altitude: 3,619 ft
Total depth: 98 ft
Depth to water: 50 ft (9-27-77)
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 62 to 93 feet; formation packer at 61 feet.

Depth	Lithologic description
0-1	Soil, clayey, tan
1-3	Claystone, reddish-brown
3-13	Sand, very fine grained, tan
13-16	Claystone, gray
16-19	Claystone, thin layers, and sandstone, very fine grained
19-28	Shale and siltstone, brown
28-32	Claystone, gray, with gypsum
32-39	Claystone, brown
39-62	Shale, carbonaceous; very carbonaceous at 55 to 62 ft
62-93	Coal
93-98	Silt and clay, gray

Test well: HWC-29B
Location: 09S44E07BBCC3
Date drilled: 5-14-77

Land-surface altitude: 3,620 ft
Total depth: 92 ft
Depth to water: 46 ft (9-27-77)
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 57 to 87 feet; formation packer at 54 feet.

Depth	Lithologic description
0-35	No log
35-57	Shale, carbonaceous; very carbonaceous from 50 to 57 ft
57-87	Coal, parting near 85 ft
87-89	Clay, gray
89-92	Silt

Test well: HWC-29C
Location: 09S44E07BBCC4
Date drilled: 5-17-77

Land-surface altitude: 3,622 ft
Total depth: 90 ft
Depth to water: 42 ft (9-27-77)
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 54 to 84 feet; formation packer at 53 feet.

Depth	Lithologic description
0-12	No log
12-15	Claystone, silty, gray
15-18	Siltstone, hard
18-23	Silt and very fine grained sandstone, brown
23-30	Claystone, reddish-brown, with gypsum
30-54	Shale, carbonaceous; very carbonaceous at 45 to 54 ft
54-85	Coal; parting near 83 ft
85-90	Clay and silt, gray

Test well: HWC-30
Location: 09S44E09CCAB
Date drilled: 5-17-77

Land-surface altitude: 3,698 ft
Total depth: 186 ft
Depth to water: 45 ft (10-77)
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 153 to 183 feet; formation packer at 149 feet.

Depth	Lithologic description
0-11	Sand, very fine grained, and silt, tan
11-18	Sand, very fine grained, tan
18-41	Gravel, very silty; subangular pebble sandstone, very fine grained; siltstone and claystone
41-50	Shale, carbonaceous, gray
50-56	Shale, carbonaceous, with coal stringers
56-71	Shale, silty, gray; with thin siltstone at 63 ft, 64 to 65 ft and 70 ft
71-85	Shale, carbonaceous, gray
85-100	Shale, gray
100-110	Shale, carbonaceous
110-137	Shale, siltstone, and sandstone, very fine grained, gray
137-153	Shale, carbonaceous
153-183	Coal
183-184	Clay, gray
184-186	Clay, silty

Test well: HWC-31
Location: 09S44E09CBCA
Date drilled: 5-26-77

Land-surface altitude: 3,680 ft
Total depth: 54 ft
Depth to water: 30 ft (6-8-77)
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 38 to 49 feet; formation packer at 33 feet.

Depth	Lithologic description
0-18	Soil, silty, brown
18-37	Sand, very fine grained, clayey, brown
37-43	Clay, brown
43-49	Gravel, pebble, subrounded to rounded; sandstone, siltstone and claystone
49-54	Clay

Test well: HWC-32
Location: 09S44E07ADAA2
Date drilled: 5-27-77

Land-surface altitude: 3,622 ft
Total depth: 25 ft
Depth to water: 6 ft (11-77)
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 11 to 22 ft; gravel packed 8 to 22 feet.

Depth	Lithologic description
0-14	Clay, silty, wet
14-21	Gravel, subangular to rounded pebble; sandstone, very fine; siltstone and claystone
21-25	Clay

Test well: HWC-33
Location: 09S44E07ADAB
Date drilled: 6-1-77

Land-surface altitude: 3,621 ft
Total depth: 24 ft
Depth to water: --
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 8 to 23 feet; gravel packed from 5 to 23 feet.

Depth	Lithologic description
0-9	Silt, clayey, brown
9-17	Gravel, very sandy and silty
17-24	Clay, gray

Test well: HWC-34
Location: 09S44E07ADAC
Date drilled: 6-2-77

Land-surface altitude: 3,621 ft
Total depth: 27 ft
Depth to water: 5 ft (6-7-77)
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 14 to 27 feet; gravel packed from 10 to 27 feet.

Depth	Lithologic description
0-14	Silt, clayey, brown
14-22	Gravel, sandy
22-27	Clay, carbonaceous, gray and black

Test well: HWC-35
Location: 09S43E12ABDD1
Date drilled: 6-10-77

Land-surface altitude: 3,575 ft
Total depth: 61 ft
Depth to water: 7 ft (8-8-77)
Sample source: cuttings

Water-well construction notes: Hole drilled with mud circulation; cased with 4-inch plastic pipe perforated from 27 to 57 feet; formation packer at 24 feet.

Depth	Lithologic description
0-15	Silt, brown
15-18	Gravel
18-25	Clay, sandy
25-57	Coal; parting near 53 ft
57-61	Clay, gray

Test well: HWC-36
Location: 09S43E12ABDD2
Date drilled: 6-14-77

Land-surface altitude: 3,575 ft
Total depth: 22 ft
Depth to water: 7 ft (11-77)
Sample source: cuttings

Water-well construction notes: Hole drilled with mud circulation; cased with 4-inch plastic pipe perforated from 12 to 22 feet.

Depth	Lithologic description
0-15	Silt, brown
15-18	Gravel and sand
18-22	Clay, sandy

Test well: HWC-37
Location: 09S43E12ADBB1
Date drilled: 6-14-77

Land-surface altitude: 3,578 ft
Total depth: 32 ft
Depth to water: --
Sample source: cuttings

Water-well construction notes: Hole drilled with mud circulation; cased with 4-inch plastic pipe perforated from 16 to 32 feet.

Depth	Lithologic description
0-16	Sand, very fine, clayey, and silt, with small gravel fraction
16-18	Gravel
18-25	Sand, clayey
25-32	Gravel, silty, pebble, with assorted rock types
32-	Coal

Test well: HWC-38
Location: 09S43E12ADBB2
Date drilled: 6-15-77

Land-surface altitude: 3,586 ft
Total depth: 40 ft
Depth to water: --
Sample source: cuttings

Water-well construction notes: Hole drilled with air and water circulation; cased with 4-inch plastic pipe perforated from 27 to 40 feet; formation packer at 2 feet.

Depth	Lithologic description
0-27	Silt, clayey, and very fine sand
27-29	Gravel
29-37	Sand, clayey
37-40	Gravel
40-	Coal

Test well: HWC-39
Location: 09S43E12ADBD
Date drilled: 6-16-77

Land-surface altitude: 3,591 ft
Total depth: 39 ft
Depth to water: 24 ft (11-77)
Sample source: cuttings

Water-well construction notes: Hole drilled with mud circulation; cased with 4-inch plastic pipe perforated from 22 to 36 feet.

Depth	Lithologic description
0-12	Silt, clayey, tan
12-30	Silt, clayey, sandy
30-36	Gravel, sandy
36-38	Clay, carbonaceous
38-39	Coal

EMRIA

(Energy Mineral Rehabilitation Inventory and Analysis)

EMRIA is a coordinated approach to field data collection, analyses, and interpretation of overburden (soil and bedrock), water, vegetation, and energy resource data. The main objective of the effort is to assure adequate baseline data for choosing reclamation goals and establishment of lease stipulations through site-specific preplanning for surface mining and reclamation.

This report is prepared through the efforts of the Department of the Interior, principally by the Bureau of Land Management and Geological Survey. Assistance is also provided by other federal and state agencies.

Reports under this effort are:

<u>EMRIA Report Number, Year</u>

1-75	Otter Creek, Montana	10-77	Beulah Trench, North Dakota
2-75	Hanna Basin, Wyoming	11-77	Pumpkin Creek, Montana
3-75	Taylor Creek, Colorado	12-77	Hanging Woman, Montana
4-75	Alton, Utah	13-77	White Tail Butte, Wyoming
5-76	Bisti West, New Mexico	14-77	Potter Mountain, Wyoming
6-76	Foidel Creek, Colorado	15-77	Henry Mountain, Utah
7-76	Red Rim, Wyoming	16-77	Emery, Utah
8-76	Bear Creek, Montana	17-77	Kimbeto, New Mexico
9-76	Horse Nose Butte, North Dakota	18-77	Fish Creek, Colorado

Reports are available from the following BLM State Offices:

COLORADO - Colorado State Office
1600 Broadway - Room 700
Denver, Colorado 80202

WYOMING - Wyoming State Office
2120 Capitol Avenue
P.O. Box 1828
Cheyenne, Wyoming 82001

MONTANA/NORTH DAKOTA -
Montana State Office
222 N. 32nd Street
P.O. Box 30157
Billings, Montana 59107

UTAH - Utah State Office
Federal Building
136 South Temple
Salt Lake City, Utah 84111

NEW MEXICO - New Mexico State Office
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P.O. Box 1449
Santa Fe, New Mexico 87501